CONTINUATION STUDY OF THE DIURNAL TEMPERATURE VARIATION OF ANTARCTICA

JAMES LEITH SAWHOOK
AND
ROBERT JOHN VOLLMER

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TEMPERATURE VARIATION OF ANTARCTICA

by

James Leith Sawhook
Lieutenant, United States Navy
B.S., University of Rochester, 1959

and

Robert John Vollmer
Commander, United States Navy
B.S., Columbia University, 1957

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ABSTRACT

Antarctica temperature variations have long puzzled researchers, giving them reason to believe that a mean diurnal temperature variation existed during the totally dark polar night. It was later found that diurnal variations were most evident when the only days averaged were those having low wind speeds and little cloud cover. This led to a conclusion that a physical explanation was not necessary and that the variation could be explained as resulting from a statistical bias.

This study is a continuation of an investigation begun at the U. S. Naval Postgraduate School in 1963 to determine whether or not a true Antarctica diurnal temperature variation exists and to determine the extent of the statistical bias effect in modifying the mean temperature variations of specially selected days. In broadening the original study, the authors utilized an additional 12 years of data, a second geographical location and more accurate methods of obtaining results.

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TABLE OF ABBREVIATIONS AND SYMBOLS

C_m	a constant which is dependent upon the meteorological influence
C_s	a constant which is dependent upon the statistical bias
F	temperature in degrees Fahrenheit
GCT	Greenwich Civil Time
g_i	Lamont correction to be applied at i^{th} observation time
hh	hour of observation
i	sequential numbering of the observation times in the cyclic period (1=0,1,2....,n)
k	subscript denoting a specific contribution to the total temperature
LST	Local Standard Time
m	subscript denoting the meteorological contribution to the total temperature
MET	meteorological temperature, free from statistical influence
mph	miles per hour
n	number of observation times in the cyclic period
OBS	observed temperature
r	subscript denoting relative temperature
s	subscript denoting the statistical bias contribution to the total temperature
t	hypothetical observed temperature equal to the sum of meteorological and statistical contributions
T_i	observed temperature at i^{th} observation time
T_{iL}	Lamont corrected temperature i^{th} observation time
$t_{rk,x}$	temperature (F) described by the listed subscripts
x	subscript equal to hh when used in conjunction with the subscript m and equal to i when used in conjunction with the subscript s

1. Introduction.

Many investigators, including Simpson, Court, Rouch and Hisdal, have observed an apparent diurnal temperature variation during the totally dark polar night season at various stations in Antarctica. In general, the averaged daily temperature curves exhibited minimum temperatures near noon, local time, and maximum temperatures near midnight. Intuitively, a diurnal temperature variation is unexpected in a region which is receiving no insolation and much effort was expended in finding a physical explanation for this phenomenon.

Simpson spent considerable time investigating the diurnal temperature variation he found at McMurdo Sound in one year's data from a Scott expedition. [11] However, he wrote in 1919 that he could report only negative results in his attempt to explain the strange temperature behavior.

Rouch, in 1941, could not find a satisfactory explanation for the daily temperature variation he found in polar night data from both Charcot and Byrd expeditions. [9]

Other investigators have, more specifically associated the diurnal temperature variation with certain types of days. Namely, they found that days with clear skies and light or moderate winds had mimimum temperatures near noon, local time whereas, overcast and windy days had a maximum temperature near noon. However, Court in 1951, was still unable to explain the phenomenon. [5]

In a study of the effect of the moon on atmospheric pres-

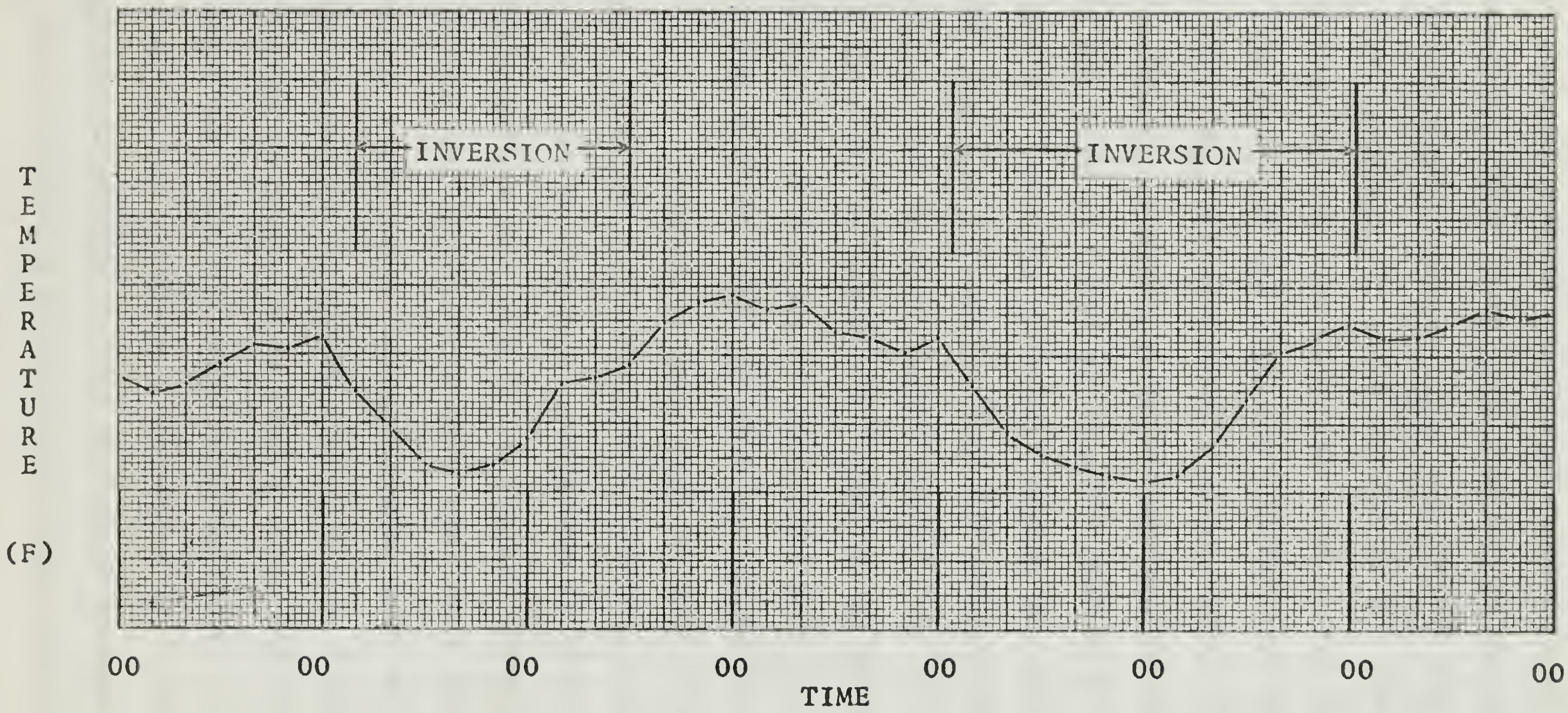
sure variations, Bartels found a similar and also unexpected diurnal pressure variation associated with specially selected days. [2] As related in his unpublished Gottingen dissertation in 1922, he determined that the pressure variation phenomenon was the result of a statistical bias induced by the day selection process. Bartels' statistical bias theory received additional support from van der Bijl as a result of his investigation of the diurnal pressure variation in northwestern Europe during specially selected days. [12]

It remained, however, for Hisdal in 1960, to independently "rediscover" that the statistical bias effect could also explain the polar night diurnal temperature variations associated with the above mentioned specific types of days. [7]

Because of the extremely cold surface in Antarctica, periods with light or moderate winds, and hence little turbulence are generally characterized by a temperature inversion. Similarly, periods with little or no cloudiness, and hence with little or no downward radiative warming, are also generally characterized by a temperature inversion. For the opposite reasons, non-inversion periods can be associated with windy and/or cloudy days. Periods during which a temperature inversion exists will thus usually exhibit lower temperature averages than non-inversion periods, but more importantly, temperature records for such periods will have similar curvature.

Figure 1 shows a hypothetical temperature curve for a period of seven days. Included are two periods characterized by temperature inversion. These periods are of unequal length

Figure 1: Hypothetical temperature curve for seven days showing periods of inversion and non-inversion.



and they do not coincide exactly with any 0000 to 24000 day. They do, however, have lower average temperatures than the non-inversion periods and their lowest temperatures occur near the middle and their highest temperatures occur at or near the end of the periods. In general, the temperature curves during the inversion periods are concave.

If all 24-hour periods, having given starting times and each totally within a period of inversion are selected from the record and the resulting mean daily (24-hour) temperature curve computed, it will be found to have the general concave shape of the longer inversion periods. If the starting time of the selected 24-hour periods is shifted, the time of occurrence of the minimum temperature of the computed mean curve will also be shifted. The shape of the mean daily temperature curve is thus partially determined by a statistical bias induced by selecting only specific 24-hour periods which individually tend to have like curvature.

For inversion-selected days, the mean temperature variation curve is therefore, composed of both the meteorological temperature variation, if any, and a statistical bias. Hisdal felt that this bias could be of sufficient magnitude to mask the true meteorological temperature variation. By implication, a sufficient number of inversion type days over a long period could result in an apparent mean diurnal variation in investigations where all days are considered.

Barrigar commenced a study at the United States Naval Postgraduate School in 1963 to determine the magnitudes of the meteorological temperature and statistical bias variation

of the mean temperature curves computed for specially selected days using six years of polar night data from McMurdo Sound, Antarctica. In addition, he computed the mean temperature variation using the data for all days during the totally dark seasons. [1]

This study is a continuation and expansion of that initiated by Barrigar. It utilizes another four years' data from McMurdo Sound and investigates a second geographical location with eight years' data from the South Pole. In this study, an additional method is employed to obtain a more accurate representation of the statistical bias than was obtained previously. A more thorough investigation is also made of the applicability of the statistical bias effect over time intervals greater and less than 24 hours. The authors briefly investigated the varying durations of the inversion periods.

2. Data and Processing.

The data, in the form of punched cards, used in this investigation was obtained from the National Weather Records Center, Asheville, North Carolina. Each punched card contains the meteorological information of one surface observation in the format described in the "Card Deck Reference Manual, 144 WBAN 1". Cards for the periods January, 1962 through October, 1965 for McMurdo Sound (78° South, 166° East) and January, 1957 through January, 1965, for Amundsen Scott station at the South Pole were received. (Figure 2 shows the locations of these stations.) Most of the card-recorded observations were at three-hour intervals although during some periods, hourly observations were available. Some observations were completely missing from Amundsen Scott station. This was particularly true in a random fashion during 1957 and again in 1964 when many of the 1500 observations were missing. In addition to this data, a magnetic tape from the study conducted by Barrigar was available. This tape contained data from McMurdo Sound at three-hour intervals during the polar night period, 15 May through 15 August, for the years 1956 through 1961.

Solar altitude curves prepared by Laevastu indicated that the duration of the dark season at McMurdo Sound is from 20 March through 20 September. [8] However, to eliminate twilight effects and any incoming solar radiation due to unusual atmospheic refraction conditions, the shorter period indicated above was used to insure total darkness at stations

during the period of investigation.

A Fortran-63 program was written for use with the Control Data Corporation 1604 (CDC 1604) digital computer to transfer the data from the McMurdo Sound tape and the new data cards to a new magnetic tape containing ten years of polar night data at that station.

Although this investigation of the Amundsen Scott (South Pole) data examines just the same three-month polar night period as that investigated at McMurdo Sound, all of the data at three-hour intervals for the South Pole was put on magnetic tape. This will enable future investigators to

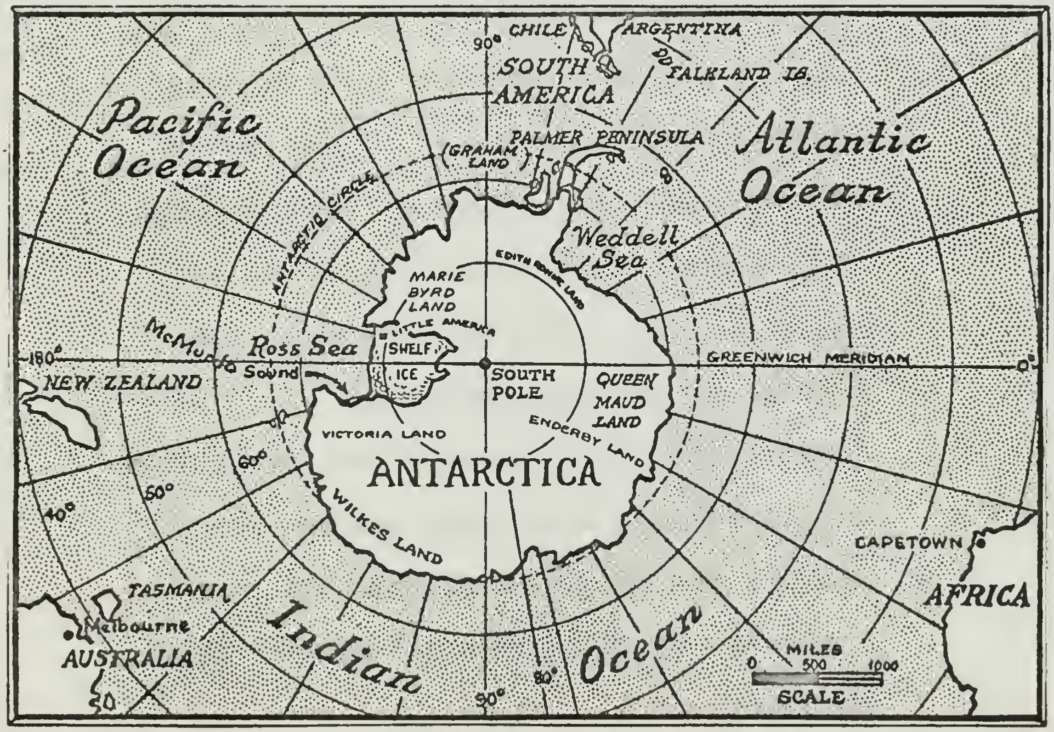


Figure 2

Geographical location of McMurdo Sound, Antarctica. Amundsen Scott station is located at the South Pole.

examine the South Pole data for any time interval.

The Fortran-63 program which was written to transfer the South Pole cards to magnetic tape incorporated several selective features. To simplify further processing, it transferred only observations at three-hour intervals, and it did not transfer cards which had missing temperature, wind, or total cloud amount data. This eliminated about 100 observations. In addition, the program converted all temperatures from three to four columns. This was necessary to make temperatures less than minus one hundred degrees compatable with the other recorded temperatures.

The magnetic data tapes were subsquently processed on the CDC 1604 digital computer, using Symbolic Coded Relocatable Assembly Program (SCRAP) to:

(1) compute for each 24-hour interval over any desired period (e.g. 15 May to 15 August) the mean values of temperature, cloudiness, atmospheric pressure, and windspeed for each observation time within the 24-hour interval;

(2) compute the total mean values determined in (1) for all the years processed;

(3) compute the means in (1) and (2) for intervals of less than or greater than 24 hours;

(4) compute the means in (1), (2), and (3) for various starting times of the interval;

(5) select the intervals for which the above

computations are made on the basis of whether or not all of the observations in the interval met the specified windspeed and cloud amount criteria;

(6) and compute the Lamont corrected values, described in section 3, of the means above.

The data tapes were also processed using Fortran-63 and SCRAP programs to compute a mean daily temperature for each specific month and day averaged over all the years possessed.

All other computations, such as column and diagonal averaging procedures detailed in section 5 were done by calculator.

3. The Lamont Correction.

The Lamont correction is a technique for modifying the values of a continuous parameter so that the values are equal at the beginning and end of a specified time period. This technique simplifies the study of cyclic variations by removing the effect of long term trends from the short term cyclic variations. The Lamont correction was utilized in this temperature study to remove the seasonal trend from the diurnal cycle.

Normally the correction is applied by modifying all values of the parameter about the value at the center of the cyclic time period to equalize the end values. This produces the graphic effect of rotating a curve about its central value until the end values are equal. The process alters the absolute values of the parameter without affecting the arithmetic mean of the time period provided the long term trend is linear. A more complete discussion of the Lamont correction is contained in Conrad and Pollak. [4]

The Lamont correction applied in the computer sub-routine mentioned in section 2 modifies all values during the cyclic period by an amount proportionate to the difference between beginning and end values of the parameter. This effectively rotates the curve about the starting value until the end value equals the starting value. This deviation from the normal procedure results in the alteration of the absolute values of the parameter and a change in the arithmetic mean. However, relative values of the parameter are preserved as

before and since only relative values of the cyclic variation are required, this simpler method is utilized.

The Lamont corrected temperatures were computed using the following equations:

$$T_{iL} = g_i + T_i \qquad (1)$$

$$g_i = \frac{i(T_0 - T_n)}{n} \qquad (2)$$

where: i = sequential numbering of the observation times in the cyclic period ($i=0,1,2,\ldots.,n$)

n = number of observation times in the cyclic period

T_i = observed temperature at i^{th} observation time

T_{iL} = Lamont corrected temperature at i^{th} observation time

g_i = Lamont correction to be applied at i^{th} observation time

As an example of Lamont's correction procedure, application of equations 1 and 2 to the hypothetical observed temperatures in table 1 yields the g_i and T_{iL} values tabulated.

TABLE 1

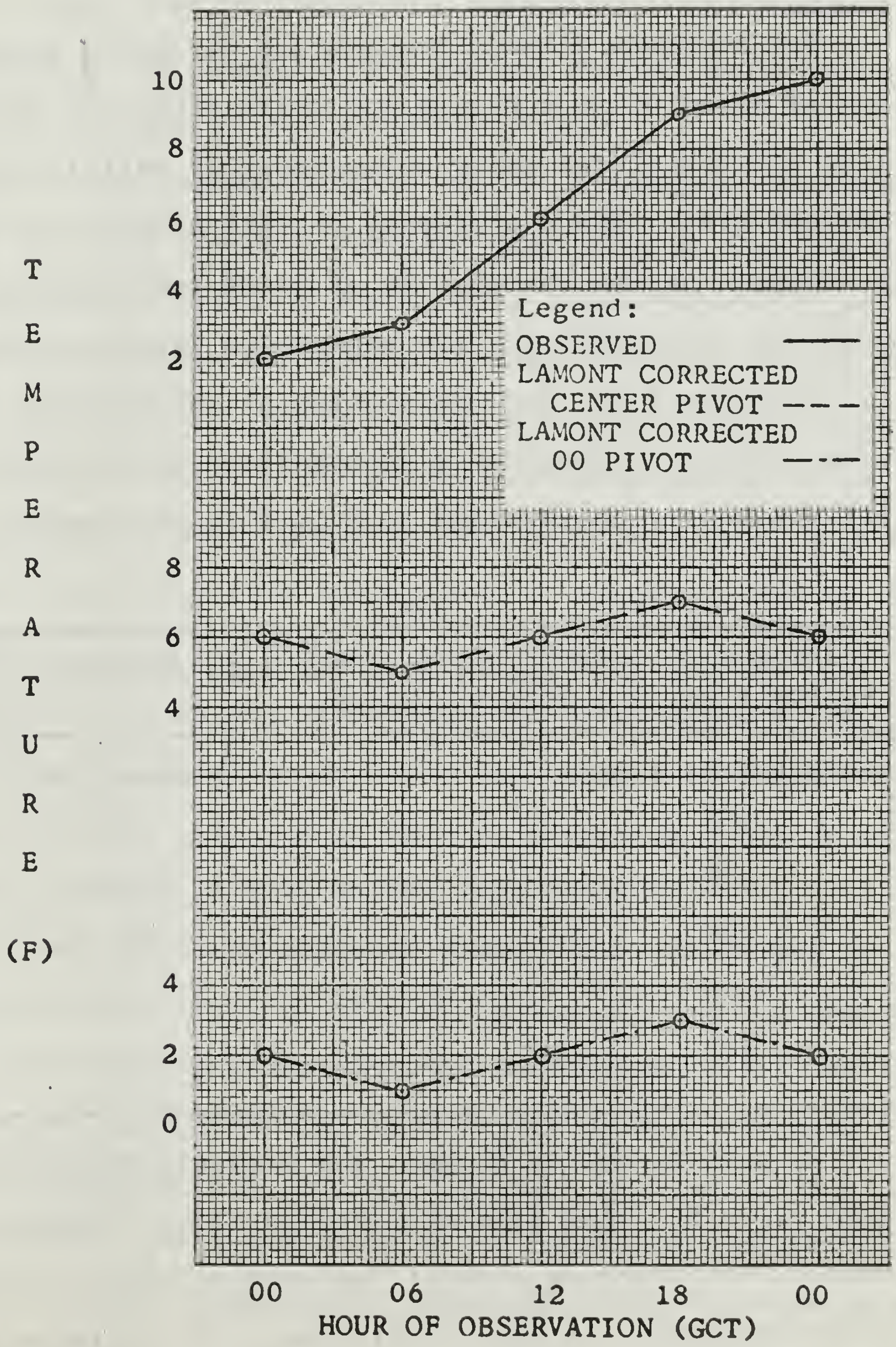
Hypothetical temperature observations (T_i) and the resulting Lamont corrected temperatures (T_{iL}).

Hour of Observation	00	06	12	18	24
i	0	1	2	3	4
T_i	2	3	6	9	12
g_i	0	-2	-4	-6	-8
T_{iL}	2	1	2	3	2

A graphical representation of the Lamont process utilizing the information in table 1 is shown in Figure 3. The observed temperature curve with a long term upward trend and Lamont corrected temperature curves which pivoted about both the central and initial temperature values are plotted. Note that the Lamont curves have different absolute temperatures but identical shapes.

Figure 3

Hypothetical observed and Lamont corrected temperature curves.



4. Theoretical Discussion of the Separation Technique.

The purpose of this section is to examine a method for separating the mean temperature variation record into its meteorological and statistical components.

The apparent diurnal temperature variation obtained for special types of days during the polar night may be considered to be the sum of the daily meteorological variation and a statistical bias. Since a purpose of this study is to determine an estimate of the variability of these two components, it is necessary to examine how the separation may be performed.

Consider first the composition of the observed temperatures. Table 2 tabulates a hypothetical statistical bias for each six-hourly observation time in a 24-hour period.

TABLE 2

Hypothetical statistical bias for each six-hourly observation time in a 24-hour period.

OBSERVATION TIME i	TEMPERATURE
0^{th}	3
1^{st}	1
2^{nd}	0
3^{rd}	1
4^{th}	3

As pointed out by Hisdal, the statistical bias is not a fixed value for each like observation time. Instead, it depends on the starting time of the special type of 24-hour period selected. If the selected day, for instance an inver-

sion day, begins at 1200, the statistical bias will be in phase with the periods' starting time and in the example of table 2, the 1200 statistical bias will be three degrees. The statistical bias is thus comparable to a free wave which moves through the meteorological temperature curve with its influence on the observed temperature record, dependent upon the starting time of the period selected.

The actual composition of the total observed temperature curves for days (24-hour periods) with various starting times selected on the basis of their being characterized by an inversion is illustrated in table 3, and in Figure 4. In table 3, the hypothetical Lamont corrected meteorological temperatures (T_{iL}) of table 1 are added to the statistical bias temperatures of table 2 at the four starting times to produce the total observed temperatures. Utilizing the values in table 3, Figure 4 illustrates the procedure graphically. The upper curve is the meteorological temperature curve which has a constant daily variation. Below it are plotted the statistical bias curves and the resulting observed temperature curves at each of the four starting times. It is readily seen that the observed temperature curves are no longer representative of the meteorological temperatures and that the time of minimum observed temperature shifts as the statistical influences are shifted due to the different starting times of the special days that were selected.

Now that the composition of the observed temperature records has been examined for specially selected days over various 24-hour periods, the next step is to examine how the

TABLE 3

Observed temperature variations resulting from the meteorological and statistical bias variations from tables 1 and 2 respectively, for various starting times.

Starting time: 0000

Hour:	00	06	12	18	00
Statistical:	3	1	0	1	3
Meteorological:	2	1	2	3	2
Observed:	5	2	2	4	5

Starting time: 0600

Hour;	06	12	18	00	06
Statistical:	3	1	0	1	3
Meteorological:	1	2	3	2	1
Observed:	4	3	3	3	4

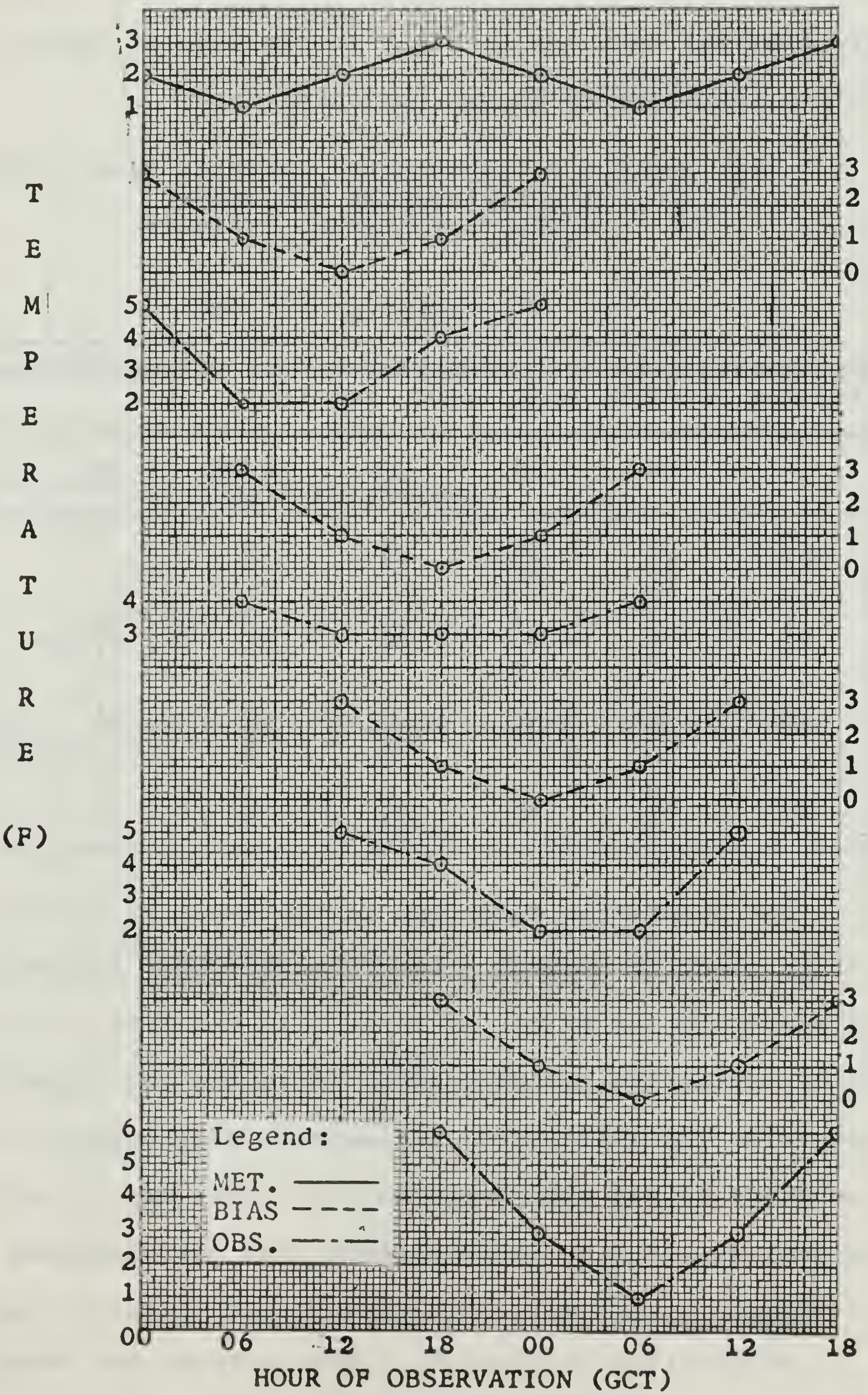
Starting time: 1200

Hour:	12	18	00	06	12
Statistical:	3	1	0	1	3
Meteorological	2	3	2	1	2
Observed:	5	4	2	2	5

Starting time: 1800

Hour;	18	00	06	12	18
Statistical:	3	1	0	1	3
Meteorological:	3	2	1	2	3
Observed:	6	3	1	3	6

Figure 4: Total observed temperature variation curves for various starting times constructed from the given meteorological and statistical bias variation curves.



original values of meteorological variation and statistical influence may be extracted from the observed temperature record. To facilitate the explanation, the previously used hypothetical data has been put in the form of table 4. The values are recorded in the following form:

t^s_m; where t = hypothetical observed temperature
s = statistical influence
m = meteorological influence

TABLE 4

Hypothetical observed temperatures for various 24-hour periods starting at 0000, 0600, 1200, and 1800.

Observation Time	00	06	12	18	24/00	06	12	18
TEMPERATURE	5^3_2	2^1_1	2^0_2	4^1_3	5^3_2			
	3^1_2	4^3_1	3^1_2	3^0_3	3^1_2	4^3_1		
	2^0_2	2^1_1	5^2_3	4^1_3	2^0_2	2^1_1	5^2_3	
	3^1_2	1^0_1	3^1_2	6^3_3	3^1_2	1^0_1	3^1_2	6^3_3

The separation technique is that used by van der Bijl in his study of diurnal pressure variations. It consists of averaging the values of table 4 in two ways: by columns to determine the meteorological influence and diagonally to determine the statistical influence. Once either of these two averages has been computed, the other may be determined by subtraction from the average of the corresponding observed values.

As detailed by Barrigar, these methods are shown below.

Notation is as follows:

trk,x where t = temperature (F)

r = (when present) denotes relative temperature

k,x = m,hh refers to meteorological influence at the indicated hour of observation

k,x = s,i refers to statistical influence at i^{th} observation time in the period

hh = hour of observation.

Averaging the observed temperatures by columns, and subtracting the constant values of the statistical bias, results in the meteorological variation.

$$t_{m,00} = \left(\frac{5+3+2+3}{4}\right) - \left(\frac{3+1+0+1}{4}\right) = \frac{13}{4} - \frac{5}{4} = 2$$

$$t_{m,06} = \left(\frac{2+4+2+1}{4}\right) - \left(\frac{1+3+1+0}{4}\right) = \frac{9}{4} - \frac{5}{4} = 1$$

$$t_{m,12} = \left(\frac{2+3+5+3}{4}\right) - \left(\frac{0+1+3+1}{4}\right) = \frac{14}{4} - \frac{5}{4} =$$

$$t_{m,18} = \left(\frac{4+3+4+6}{4}\right) - \left(\frac{1+0+1+3}{4}\right) = \frac{17}{4} - \frac{5}{4} = 3$$

$$t_{m,24} = \left(\frac{5+3+2+3}{4}\right) - \left(\frac{3+1+0+1}{4}\right) = \frac{13}{4} - \frac{5}{4} = 2$$

Averaging the observed temperatures and subtracting the constant value of the meteorological influence, results in

the statistical influence.

$$t_{s,0} = \left(\frac{5+4+5+6}{4}\right) - \left(\frac{2+1+2+3}{4}\right) = \frac{20}{4} - \frac{8}{4} = 3$$

$$t_{s,1} = \left(\frac{2+3+4+3}{4}\right) - \left(\frac{1+2+3+2}{4}\right) = \frac{12}{4} - \frac{8}{4} = 1$$

$$t_{s,2} = \left(\frac{2+3+2+1}{4}\right) - \left(\frac{2+3+2+1}{4}\right) = \frac{8}{4} - \frac{8}{4} = 0$$

$$t_{s,3} = \left(\frac{4+3+2+3}{4}\right) - \left(\frac{3+2+1+2}{4}\right) = \frac{12}{4} - \frac{8}{4} = 1$$

$$t_{s,4} = \left(\frac{5+4+5+6}{4}\right) - \left(\frac{2+1+2+3}{4}\right) = \frac{20}{4} - \frac{8}{4} = 3$$

In this example, the originally assumed values of the meteorological and statistical influences have been recovered. In actual practice, however, the only known values are those of the observed temperatures. The constant terms just subtracted from the observed temperature values are unknown but they may be determined as follows:

Using the additional notation:

C_m = a constant which is dependent upon the meteorological influence

C_s = a constant which is dependent upon statistical bias

the previously computed averages become:

$$t_{m,00} = \frac{13}{4} - C_s$$

$$t_{m,06} = \frac{9}{4} - C_s$$

$$t_{m,12} = \frac{13}{4} - C_s$$

$$t_{m,18} = \frac{17}{4} - C_s$$

$$t_{m,24} = \frac{13}{4} - C_s$$

$$C_s = \frac{t_{s,0} + t_{s,1} + t_{s,2} + t_{s,3}}{4}$$

Using 0000 as the starting time, the previously computed diagonal averages become:

$$t_{s,0} = \frac{20}{4} - C_m$$
$$t_{s,1} = \frac{12}{4} - C_m$$
$$t_{s,2} = \frac{8}{4} - C_m$$
$$t_{s,3} = \frac{12}{4} - C_m$$
$$t_{s,4} = \frac{20}{4} - C_m$$
$$C_m = \frac{t_{m,00} + t_{m,06} + t_{m,12} + t_{m,18}}{4}$$

Making the appropriate substitution for C_m in the last set of equations:

$$\begin{aligned}
t_{s,0} &= \frac{20}{4} - \frac{t_{m,00} + t_{m,06} + t_{m,12} + t_{m,18}}{4} \\
&= \frac{20}{4} - \frac{1}{4}\left[\left(\frac{13}{4} + \frac{9}{4} + \frac{13}{4} + \frac{17}{4}\right) - 4C_s\right] \\
&= \frac{20}{4} - \frac{1}{4}\left(\frac{13+9+13+17}{4}\right) - \left(\frac{t_{s,0} + t_{s,1} + t_{s,2} + t_{s,3}}{4}\right) \\
&= 5 - \frac{52}{16} - (t_{s,0} + t_{s,1} + t_{s,2} + t_{s,3})/4
\end{aligned}$$

$$\therefore\ 3t_{s,0} - t_{s,1} - t_{s,2} - t_{s,3} = 7 \qquad (3)$$

Similarily, for the starting times at 0600, 1200 and 1800, we obtain, respectively:

$$t_{s,0} - 3t_{s,1} + t_{s,2} + t_{s,3} = 1 \qquad (4)$$

$$t_{s,0} + t_{s,1} - 3t_{s,2} + t_{s,3} = 5 \qquad (5)$$

$$t_{s,0} + t_{s,1} + t_{s,2} - 3t_{s,3} = 1 \qquad (6)$$

Equations (3) through (6) comprise a set of four linear, homogeneous equations in four unknowns, which can be solved using the usual mathematical techniques. The solution yields the following statistical bias temperatures:

$t_s,0 = 3$

$t_s,1 = 1$

$t_s,2 = 0$

$t_s,3 = 1$

$t_s,4 = t_s,0 = 3.$

These are the originally assumed values and subtracting from the appropriate observed temperatures yields the original meteorological temperature.

By solving sets of equations, it is thus possible to determine the actual values of the statistical and meteorological constituents. However, it will be shown in the next section that for the purposes of this study, it is not necessary to determine the constants C_s and C_m.

5. Discussion of the Separation Technique Used in This Study

The purpose of this section is to illustrate the technique employed in this study for the separation of the mean observed temperature variation curves for selected periods into their meteorological and statistical components. The SCRAP program mentioned in section 2 computes the average observed temperature at each observation time for the "days" selected of specified length and starting times. These are represented by the observed temperatures listed in table 4. The hourly meteorological and statistical contributions are unknown. As shown in the previous section, it is necessary to solve a set of linear homogeneous equations to determine the specific values of statistical bias and meteorological effect. In fact, the equation sets would consist of eight equations instead of four as illustrated in the example. This is a result of our determining the mean temperatures at three-hour intervals instead of the examples' six-hour intervals in order to obtain more detail temperature variation curves.

As this study is concerned with the shapes of the temperature curves and not with the absolute temperature curves and not with the absolute temperature values, it is sufficient to determine the relative values of the meteorological and statistical temperature constituents.

By using the procedure of section 4, the observed temperatures in table 4 are column averaged to determine the meteorological influence. If the constant C_S values are now neglected, the remaining numerical values become relative

values of the meteorological temperature at each hour as shown below where the subscript r denotes relative values.

Column Averages	Relative Meteorological Values
$t_{m,00} = \frac{13}{4} - C_s$	$t_{rm,00} = \frac{13}{4} = 3.25$
$t_{m,06} = \frac{9}{4} - C_s$	$t_{rm,06} = \frac{9}{4} = 2.25$
$t_{m,12} = \frac{13}{4} - C_s$	$t_{rm,12} = \frac{13}{4} = 3.25$
$t_{m,18} = \frac{17}{4} - C_s$	$t_{rm,18} = \frac{17}{4} = 4.25$
$t_{m,24} = \frac{13}{4} - C_s$	$t_{rm,24} = \frac{13}{4} = 3.25$

Subtracting these relative values from the appropriate observed temperatures, yields the relative value of statistical bias for each hour as shown:

$$t_{rs,0} = 5 - 3.25 = 1.75$$

$$t_{rs,1} = 2 - 2.25 = -.25$$

$$t_{rs,2} = 2 - 3.25 = -1.25$$

$$t_{rs,3} = 4 - 4.25 = -.25$$

$$t_{rs,4} = 5 - 3.25 = 1.75$$

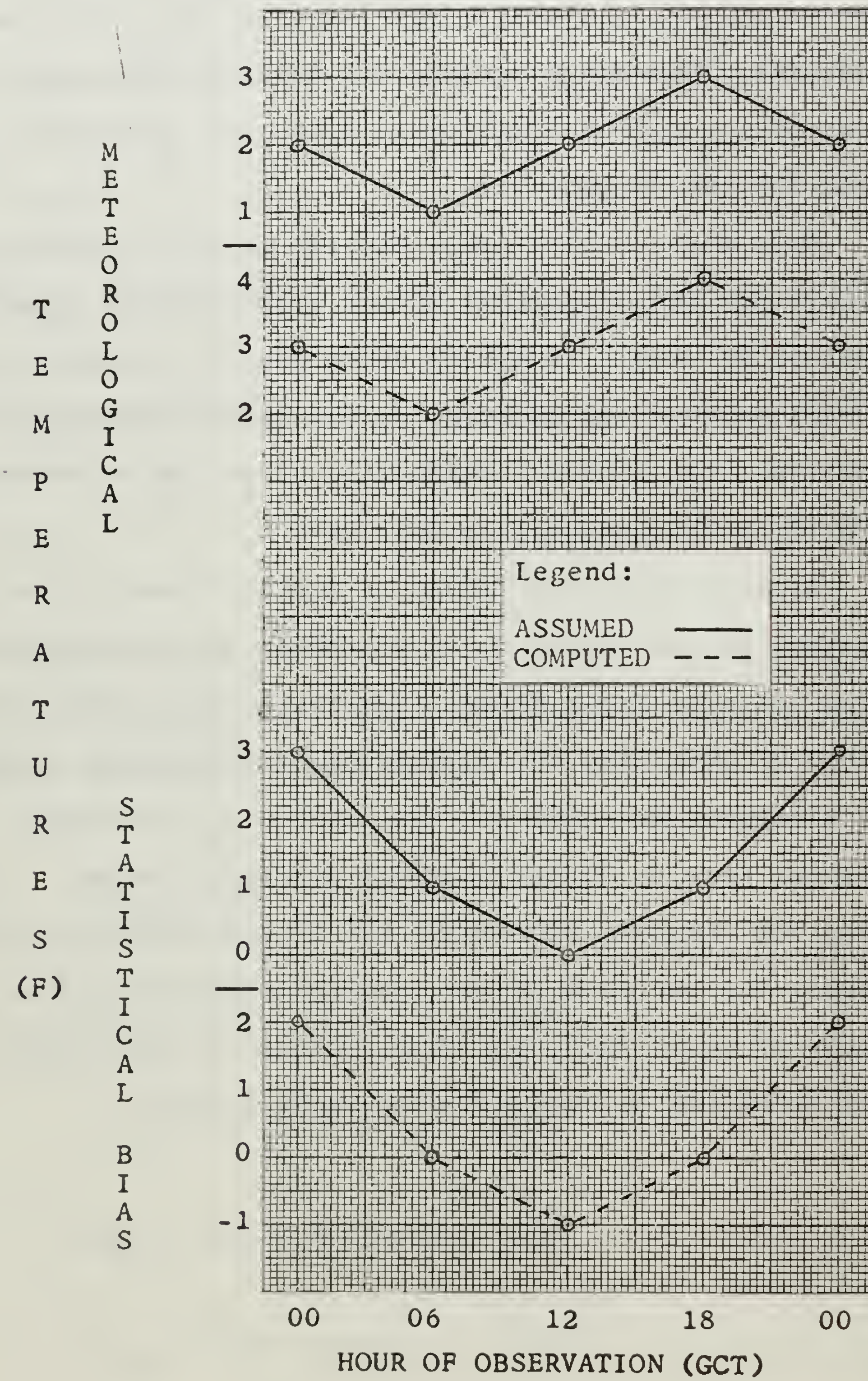
The originally assumed and just determine meteorological and statistical bias temperatures are plotted in figure 5. Although the numerical values of the original and relative values are different, the shapes of the curves are identical. The above example utilized the observed temperatures of the period starting at 0000, but the method is applicable for any period.

Note that in this procedure the relative meteorological temperature was determined before computing the relative statistical bias. It can be shown that by averaging diagonally, eliminating the constant C_m and making appropriate subtractions, the relative statistical bias can be determined before the meteorological temperature.

Because of the existence of random errors in the data utilized in the study, it is desirable to use computations which minimize their effect. Barrigar showed that the best method of obtaining the meteorological influence is by column averaging and that the best method for obtaining the statistical bias is by the diagonal averaging method. In fact, using the diagonal instead of the column averaging procedure reduces the variance in the computed statistical bias by a factor of seven where the observations are three hours apart. Both averaging methods are used in this study.

Figure 5

Assumed and computed relative values of meteorological and statistical bias temperatures.



6. General Discussion of the Results.

The results for the McMurdo Sound and South Pole stations are individually presented in the following two sections. As described previously, the data reduction and processing led to a series of temperature variation curves for each of the stations. A set of curves consisting of the mean observed meteorological and statistical bias temperatures for the specified intervals has been drawn for each of the various selection criteria utilized. Each of the sets of curves consists of a Figure a and a Figure b. The meteorological and statistical bias variations of the a Figures were computed using the previously mentioned column averaging method. Figure b variation curves were computed using the diagonal averaging method. The a Figures thus contain the most representative meteorological temperature curves and the b Figures the most representative statistical bias curves. In each instance, the mean temperature variation curve is that of the interval beginning at 0000.

The frequent significant variations in the curves computed using the two methods justifies the additional diagonal averaging computations which were not utilized in the previous study. As an example, note the difference in the statistical bias curves of Figures 17a and 17b.

For easy reference, tables 5 and 6 list the number of periods meeting the various selection criteria at the MuMurdo Sound and South Pole stations, respectively. In comparing the curves which follow, it is important to realize that the

same temperature scale is not utilized on each figure.

TABLE 5

The number of periods at McMurdo Sound meeting each of the specified selection criteria.

Selection Criteria			Number of Days Meeting Selection Criteria
Windspeed (mph)	Cloud Cover (tenths)	Length of Period (hours)	
≤ 5	≤ 5	24	68
≤ 10	≤ 5	24	156
≤ 15	≤ 5	24	244
≤ 15	≤ 5	18	357
≤ 15	≤ 5	36	91
≤ 15	≤ 5	48	50
≤ 15	≤ 5	60	30
≤ 15	≤ 5	72	22
> 15	> 5	24	78
all	< 5	24	710
all	> 5	24	458
≤ 15	all	24	607
> 15	all	24	183

TABLE 6

The number of periods at the South Pole meeting each of the specified selection criteria.

Selection Criteria			Number of Days Meeting Selection Criteria
Windspeed (mph)	Cloud Cover (tenths)	Length of Period (hours)	
$\leq$ 10	$\leq$ 5	24	20
$\leq$ 15	$\leq$ 5	24	442
$\leq$ 20	$\leq$ 5	24	828
$\leq$ 30	$\leq$ 5	24	1217
$\leq$ 45	$\leq$ 5	24	1217
$>$15	$>$5	24	86
$>$30	$>$5	24	0
$>$30	all	24	0
$>$15, $\leq$ 30	$\leq$ 5	24	111
$>$15, $\leq$ 30	$>$ 5	24	30
$>$20, $\leq$ 30	$>$ 5	24	2
$>$20, $\leq$ 30	$\leq$ 5	24	2

7. Results of McMurdo Sound Data.

Figure 6 shows the mean daily temperature variation determined by each observation time over all consecutive 0000 to 2400 periods during the polar night. The range between the maximum and minimum values is 0.22 degrees (F) which leads to the authors' contention that there is no diurnal temperature variation at McMurdo Sound. The same curve computed by Barrigar with just six years of data had a variation of 0.5 degrees (F) and it is felt that the mean diurnal variations reported by early investigators would not have been found, had additional data been available to them. Figure 7 shows the mean temperature variation averaged at each observation time over all consecutive 48-hour periods. With only half as many intervals being averaged as in Figure 6, the temperature range has increased to 0.4 degrees (F). However, there is no correspondence between the first and last 24-hour periods of the curve as would be the case if a true diurnal temperature variation did exist. Note that the first 2100 observation temperature is a relative maximum, while the temperature at the second is the curve's minimum.

Figure 8 represents the mean seasonal trend of the temperature, averaged daily using the ten years of data available. The curve shows the general long term, downward trend expected during the polar night. The considerable aperiodic fluctuations reflect the variability of temperature during the polar night due to radiative as well as atmospheric circulation effects.

Figure 6

Mean temperature variation at McMurdo Sound averaged for all days during the polar night for the years 1956-1965. Two temperature scales are illustrated.

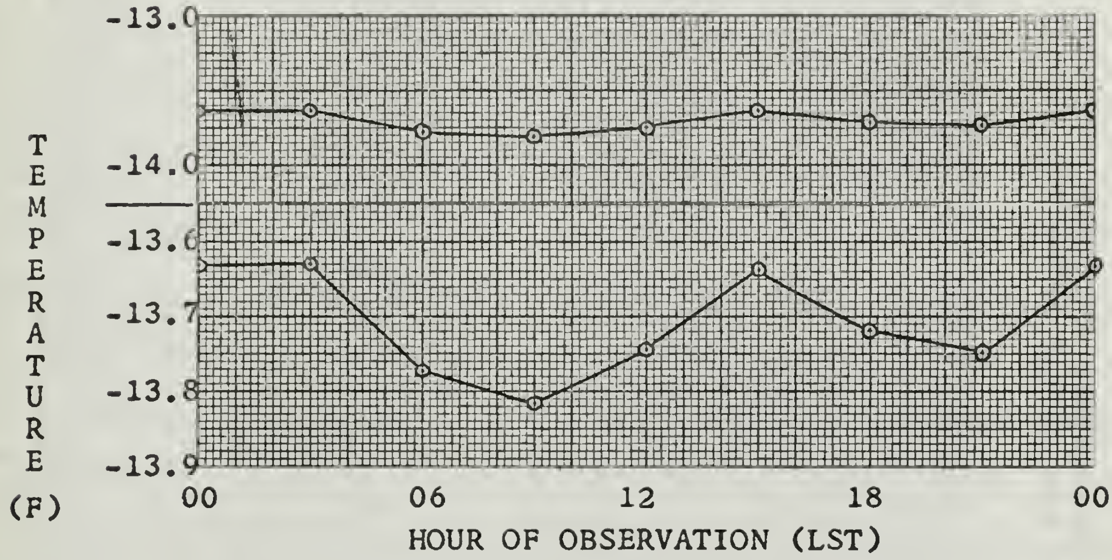


Figure 7

Mean temperature variation at McMurdo Sound averaged for all consecutive 48-hour periods.

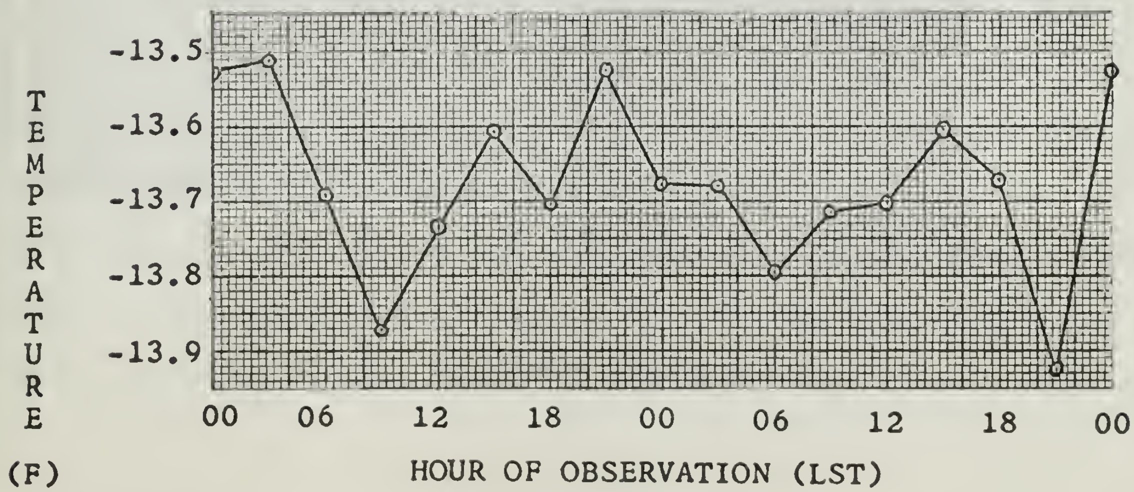
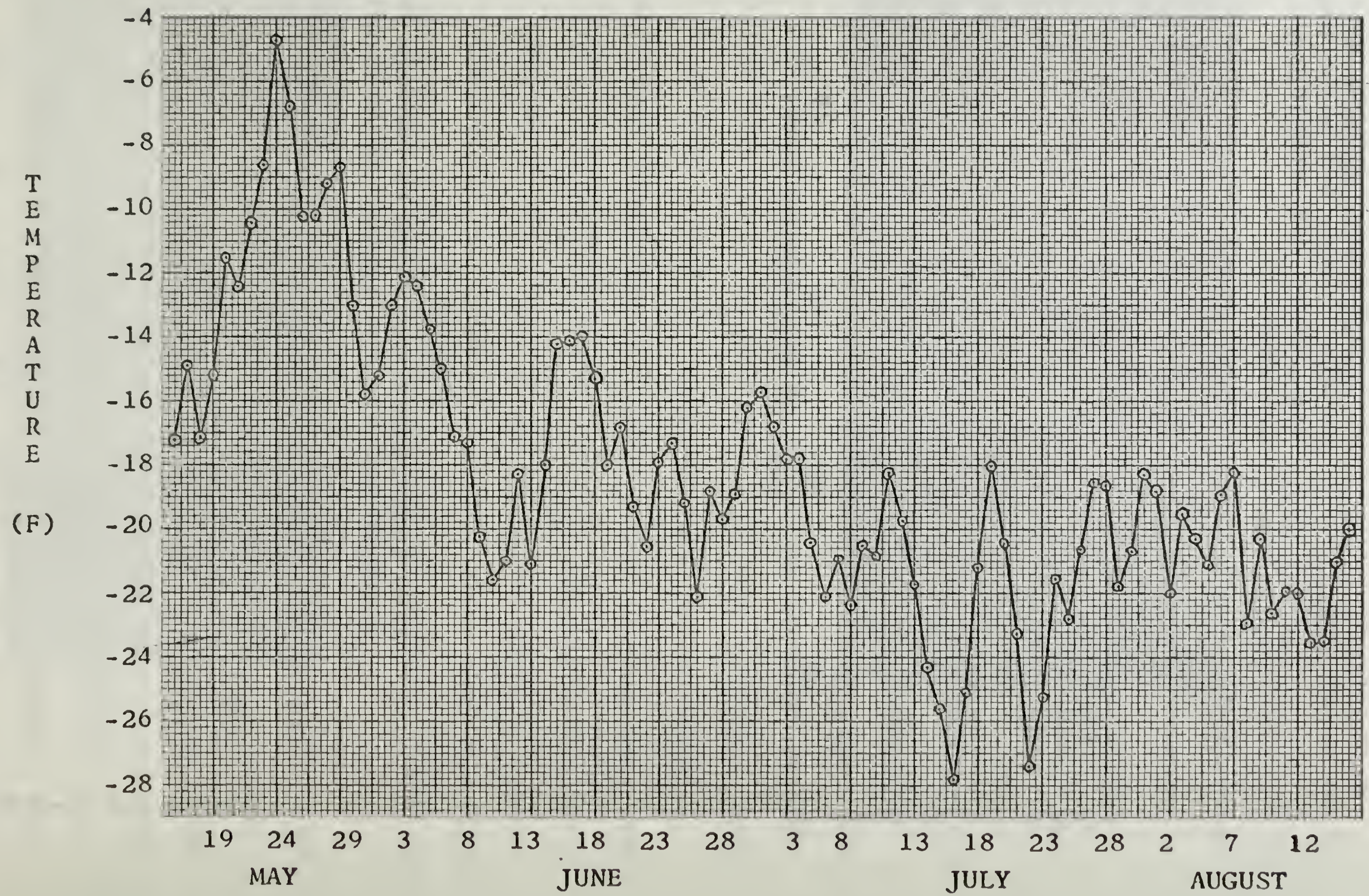


Figure 8

Mean seasonal trend of the temperature at McMurdo Sound, averaged daily during the period 1956-1965.



Barrigar's results supported Hisdal's suggestion that windspeeds $\leq$ 15 mph and cloudiness $\leq$ 5/10 were the optimum criteria for the selection of inversion type days. The results of the authors' use of these selection criteria are shown in Figure 9. The curves have almost the exact same shapes as Barrigar's, although the new data increased the number of 24-hour periods meeting the criteria from 174 to 244. The mean temperature curve exhibits a diurnal fluctuation and the Figure 9b statistical bias curve has the expected convex shape with an almost one degree range between its maximum and minimum values. The Figure 9a meteorological temperature curve does, however, show a diurnal variation of 1.1 degrees (F) indicating the existence of a slight diurnal temperature variation for the days selected.

Figures 10 and 11 show the results for selected days with windspeeds $\leq$ 10 and $\leq$ 5 mph respectively, and it is noted that as the selection criteria became more restrictive, the number of periods meeting the criteria decreased. It was anticipated that as the criteria for maximum allowable windspeed was decreased, the inversion effect would become stronger, resulting in increased concave curvature of the statistical bias curves. The average temperatures of the mean temperature variation curves decreases as the windspeeds are reduced, indicating intensification of the inversion, but the corresponding increase in the statistical bias effect is lacking as seen in studying Figures 9b, 10b and 11b. This can most probably be attributed to the increased effect of random-

Figure 9a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

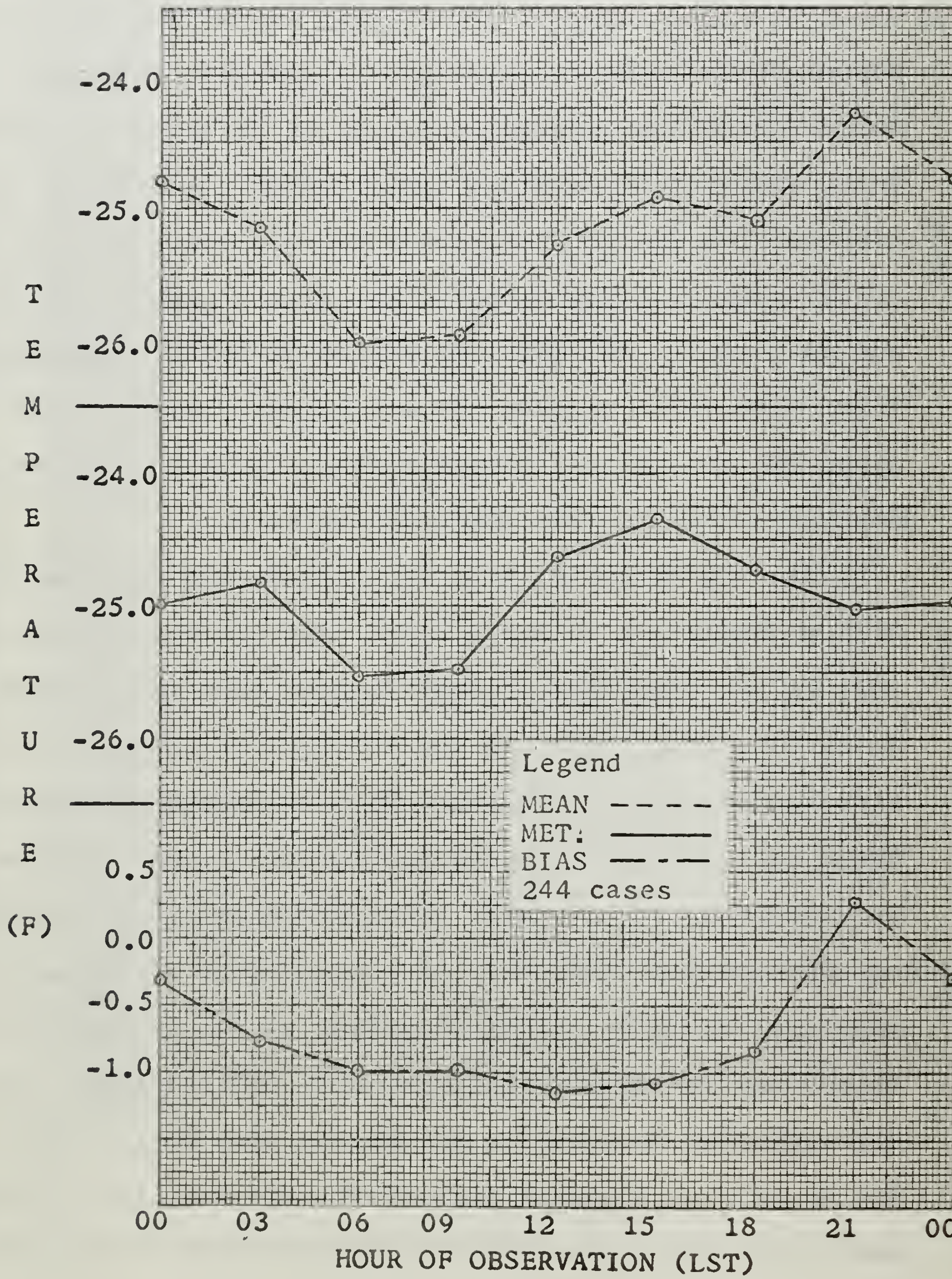


Figure 9b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

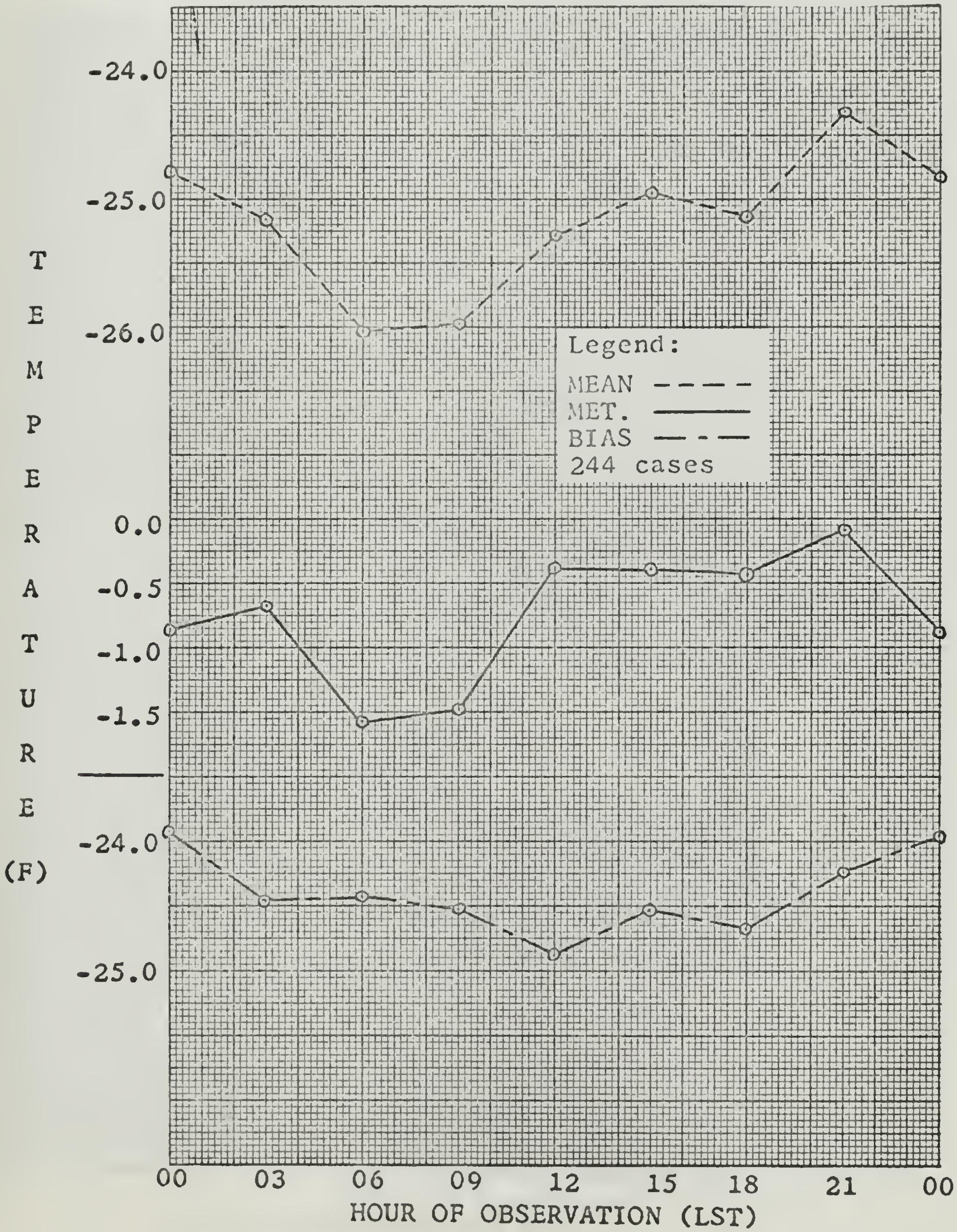


Figure 10a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 10 mph; cloudiness ≤ 5/10)

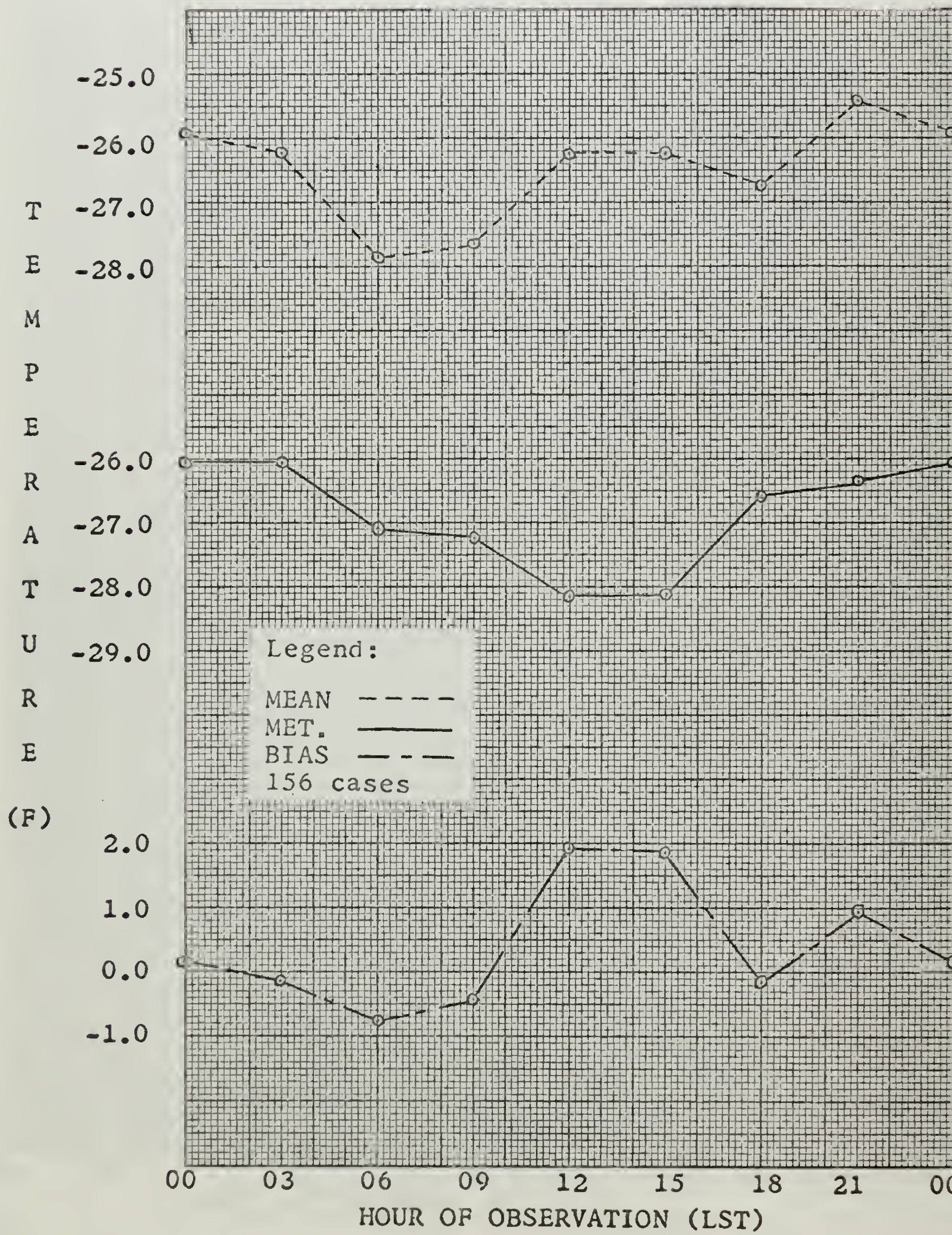


Figure 10b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 10 mph; cloudiness ≤ 5/10)

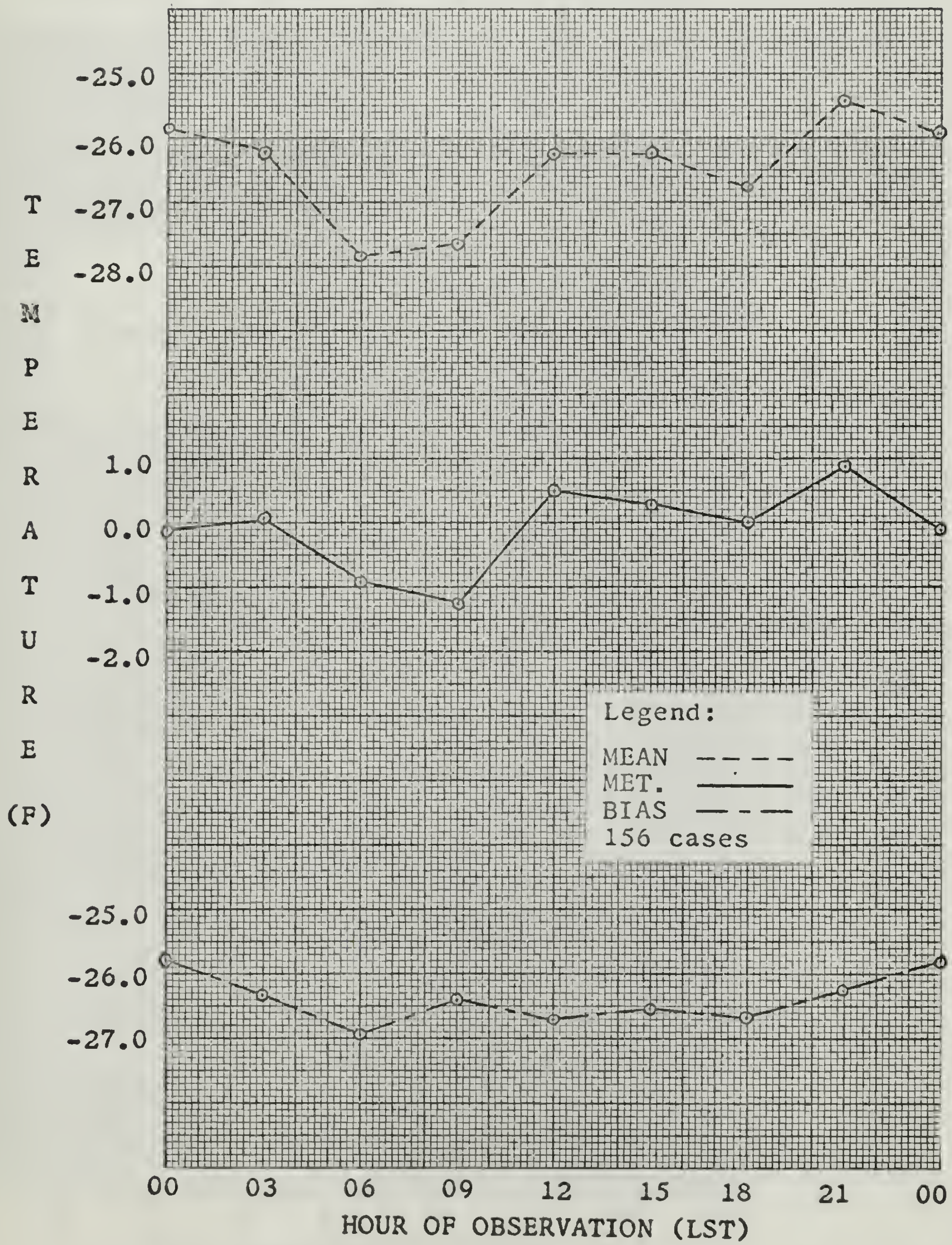


Figure 11a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 5 mph; cloudiness ≤ 5/10)

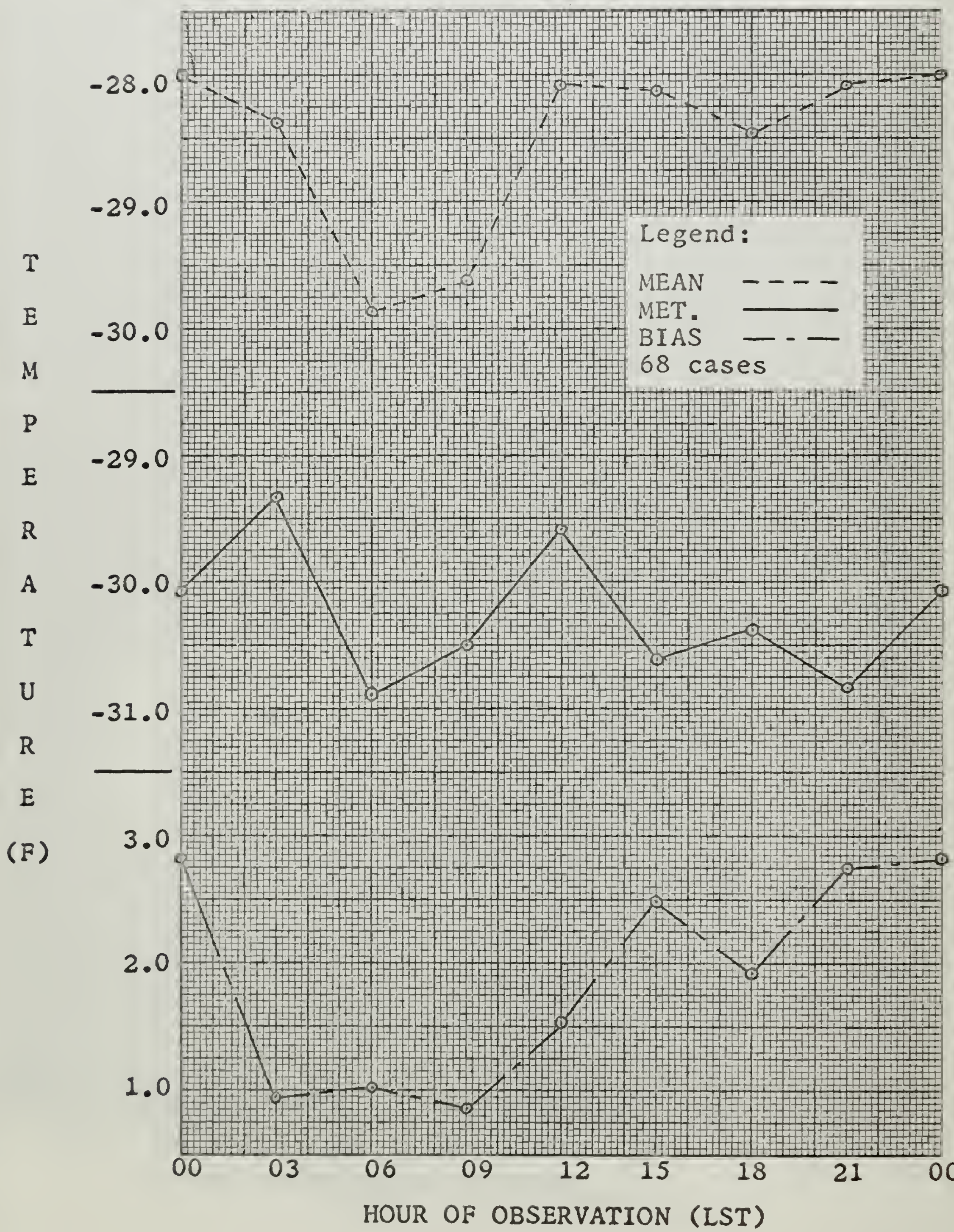
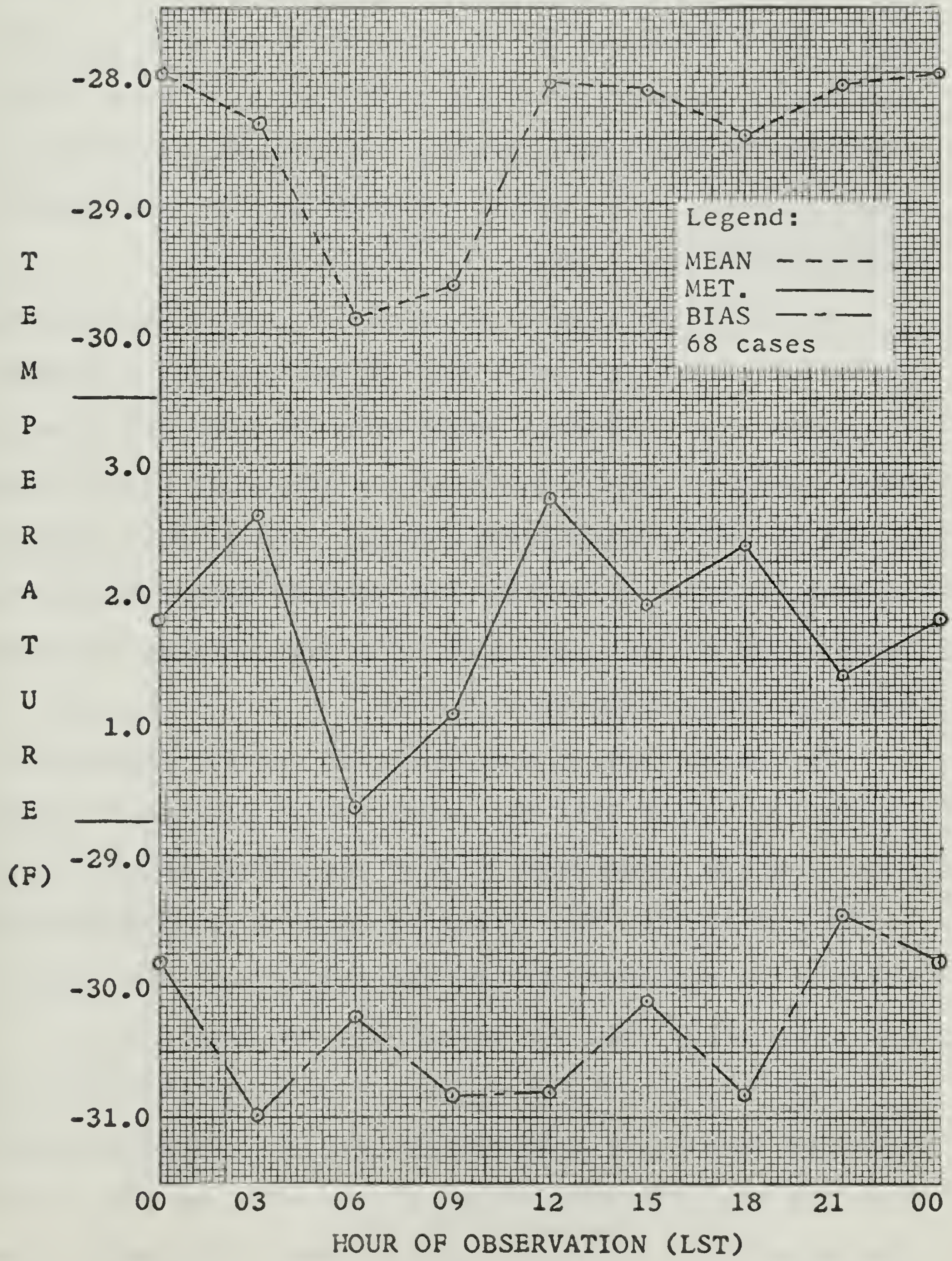


Figure 11b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 5 mph; cloudiness ≤ 5/10)



ness in the data as the number of periods meeting the selection criteria was reduced.

The randomness effect is also evidenced in noting the increased variations between the statistical bias curves of the a and b figures. It is interesting to note the cases meeting the various selection criteria are few in number compared to the over 3600 possible 24-hour periods in the ten years of data. This number is based on the four starting times used in the study.

In all three figures of this set, the mean temperature variation curves are quite similar and suggest a diurnal variation with a minimum temperature at 0600 and a maximum near midnight. The meteorological variation curves, however, do not show similar correspondence. Indeed they exhibit a variety of times of maximum and minimum temperatures, and cannot lead to the conclusion of a true diurnal temperature variation for inversion type days.

The second set of McMurdo Sound curves, Figures 12 through 16 result from the selection of periods of varying length having cloud cover $\leq$ 5/10 and windspeeds $\leq$ 15 mph. Periods of 18, 36, 48, 60 and 72 hours were selected to determine the applicability of the statistical bias effect over intervals other than the normal 24-hour day.

From Figure 12b, it is seen that a smooth concave statistical bias curve resulted for the 357, 18-hour periods that met the selection criteria. However, as the length of the interval is increased, and the number of periods meeting the criteria is decreased, the statistical bias curves become

Figure 12a: Comparison of the mean 18-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

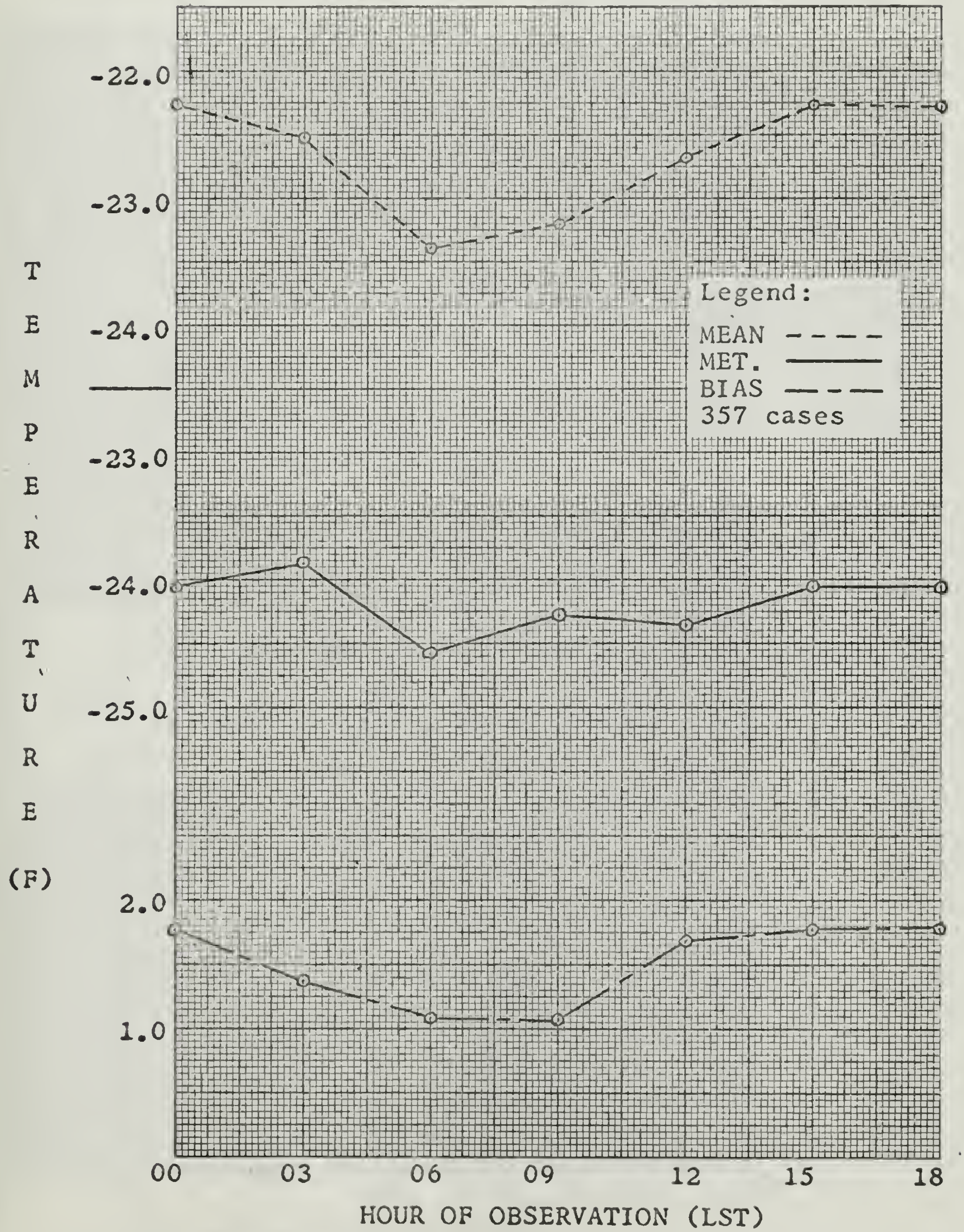


Figure 12b: Comparison of the mean 18-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

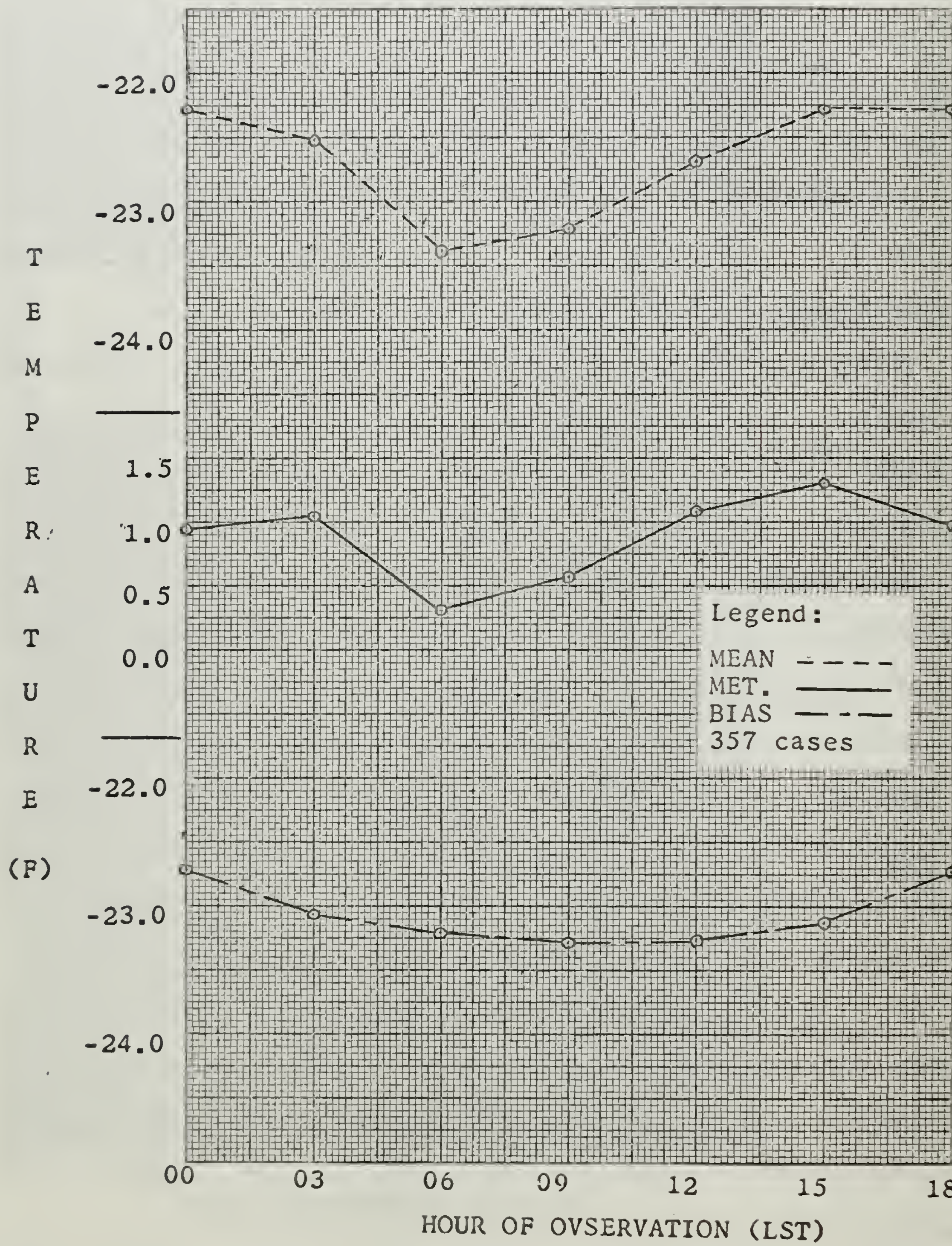


Figure 13a: Comparison of the mean 36-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed $\leq$ 15 mph; cloudiness $\leq$ 5/10)

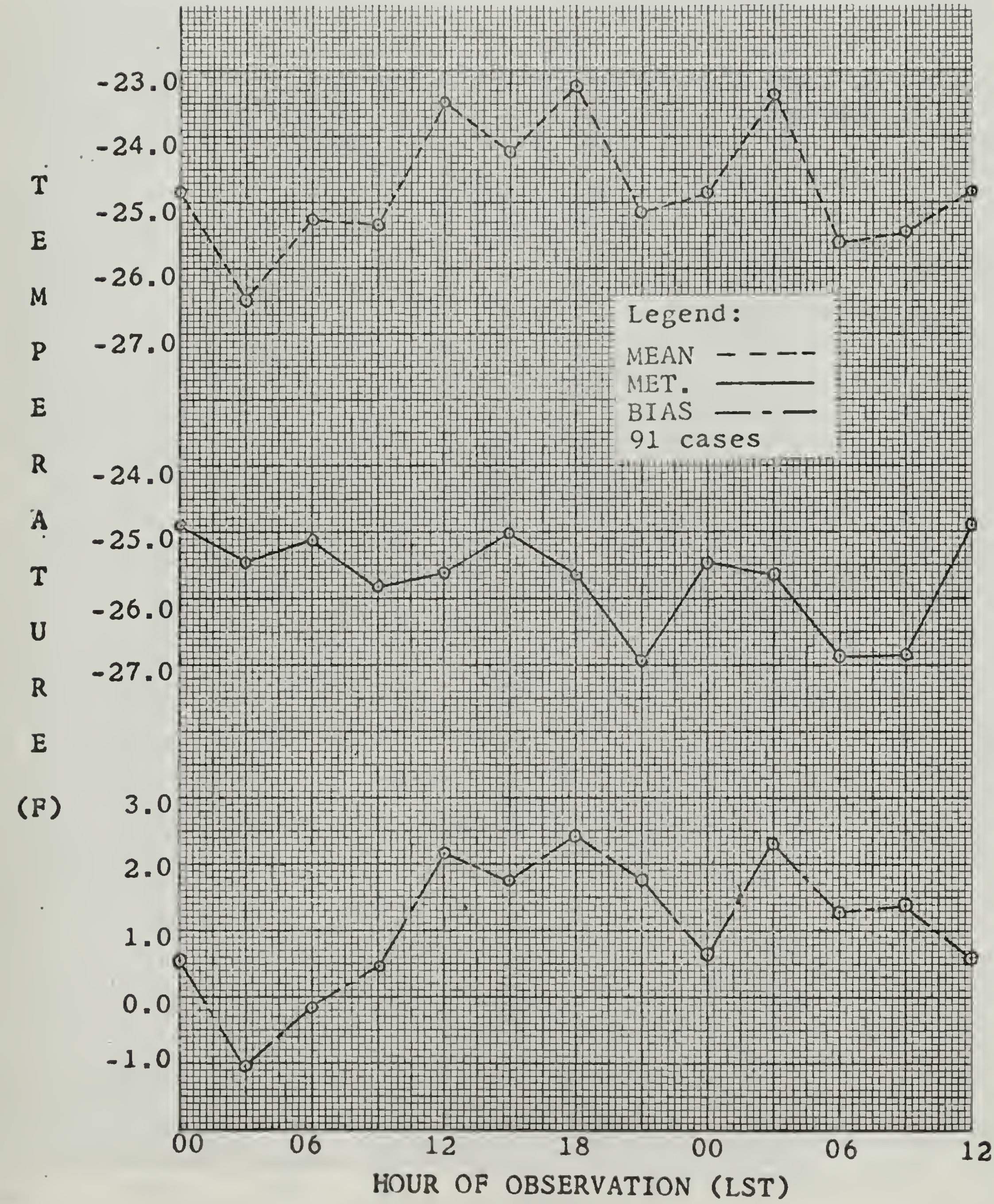


Figure 13b: Comparison of the mean 36-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

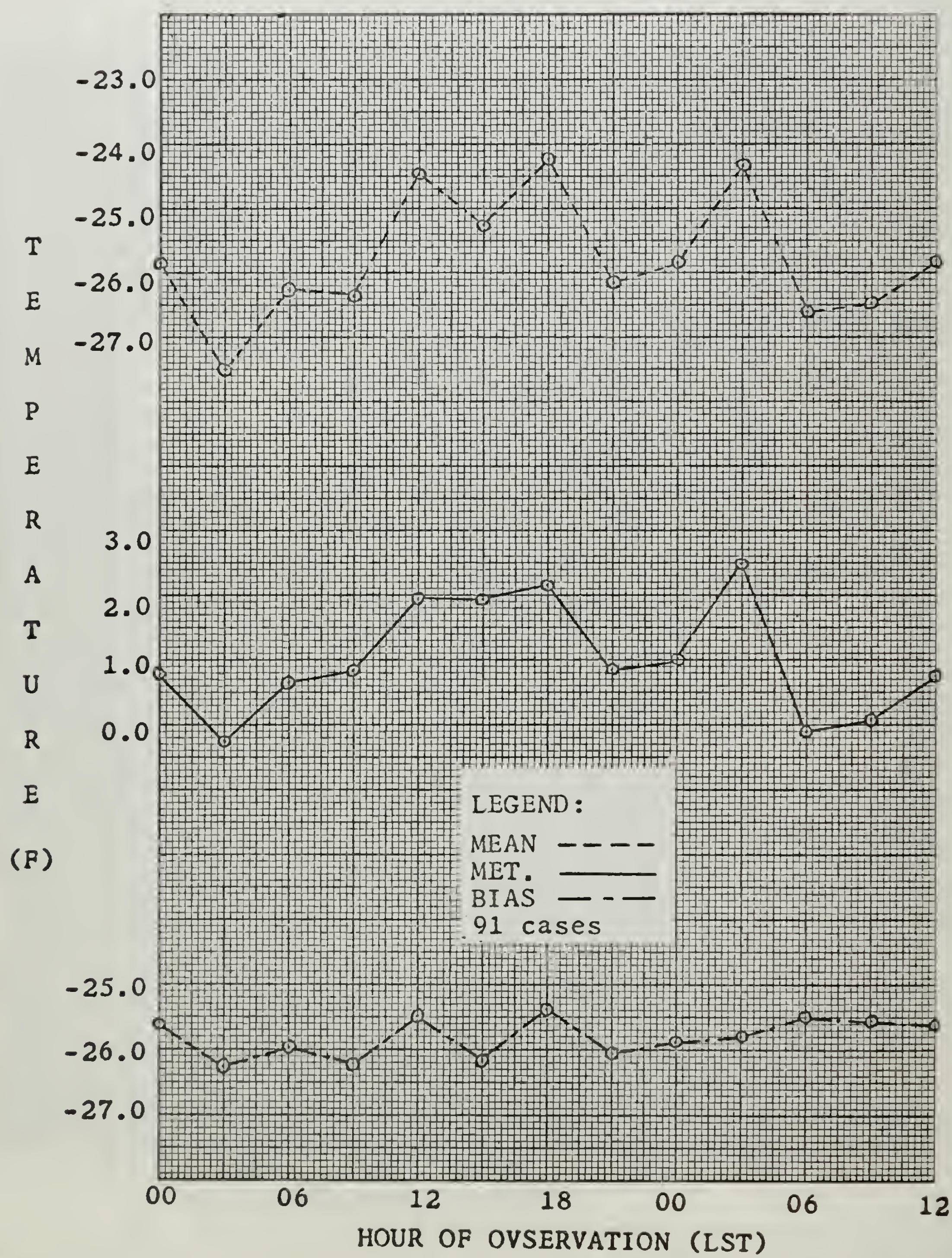


Figure 14a: Comparison of the mean 48-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

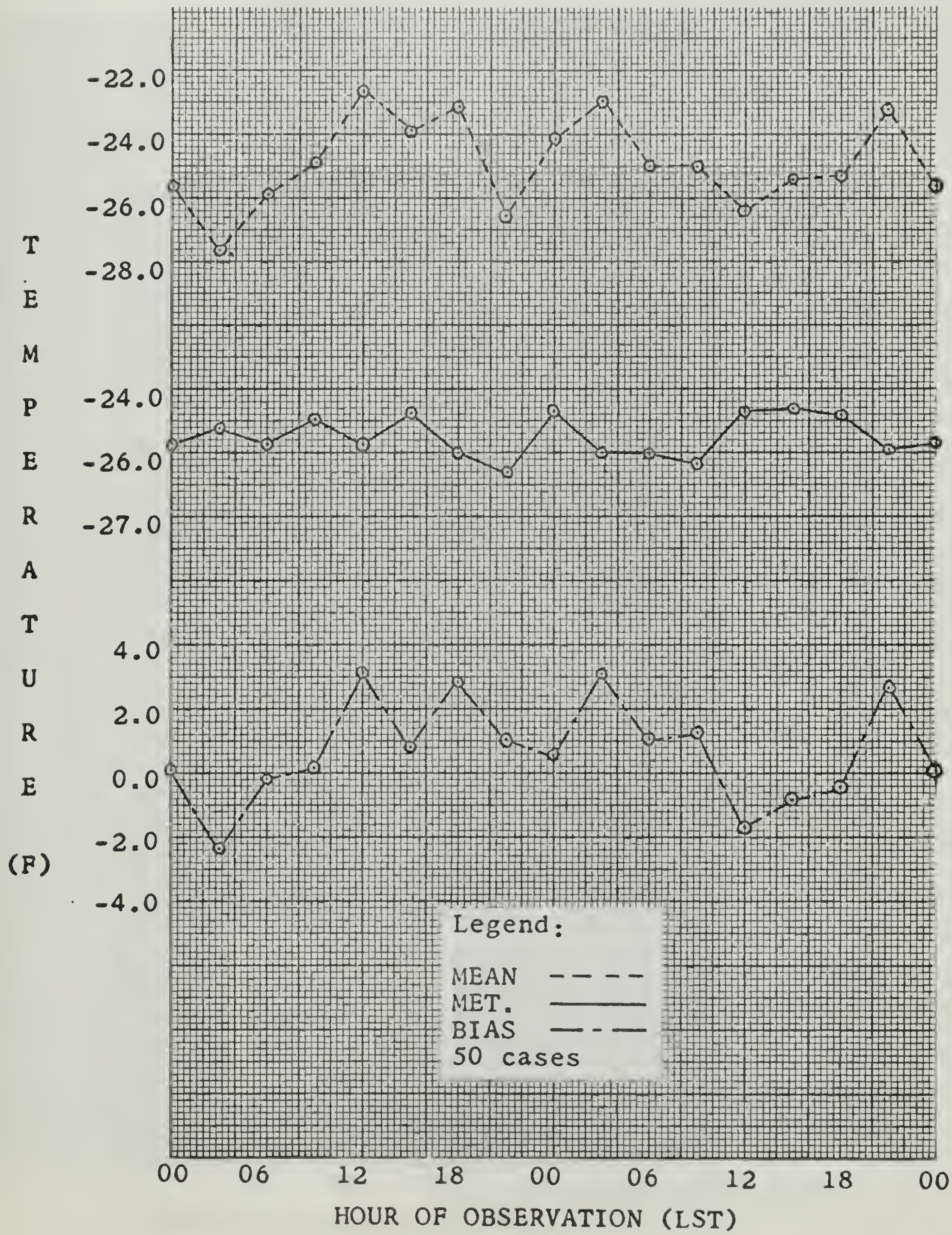


Figure 14b: Comparison of the mean 48-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

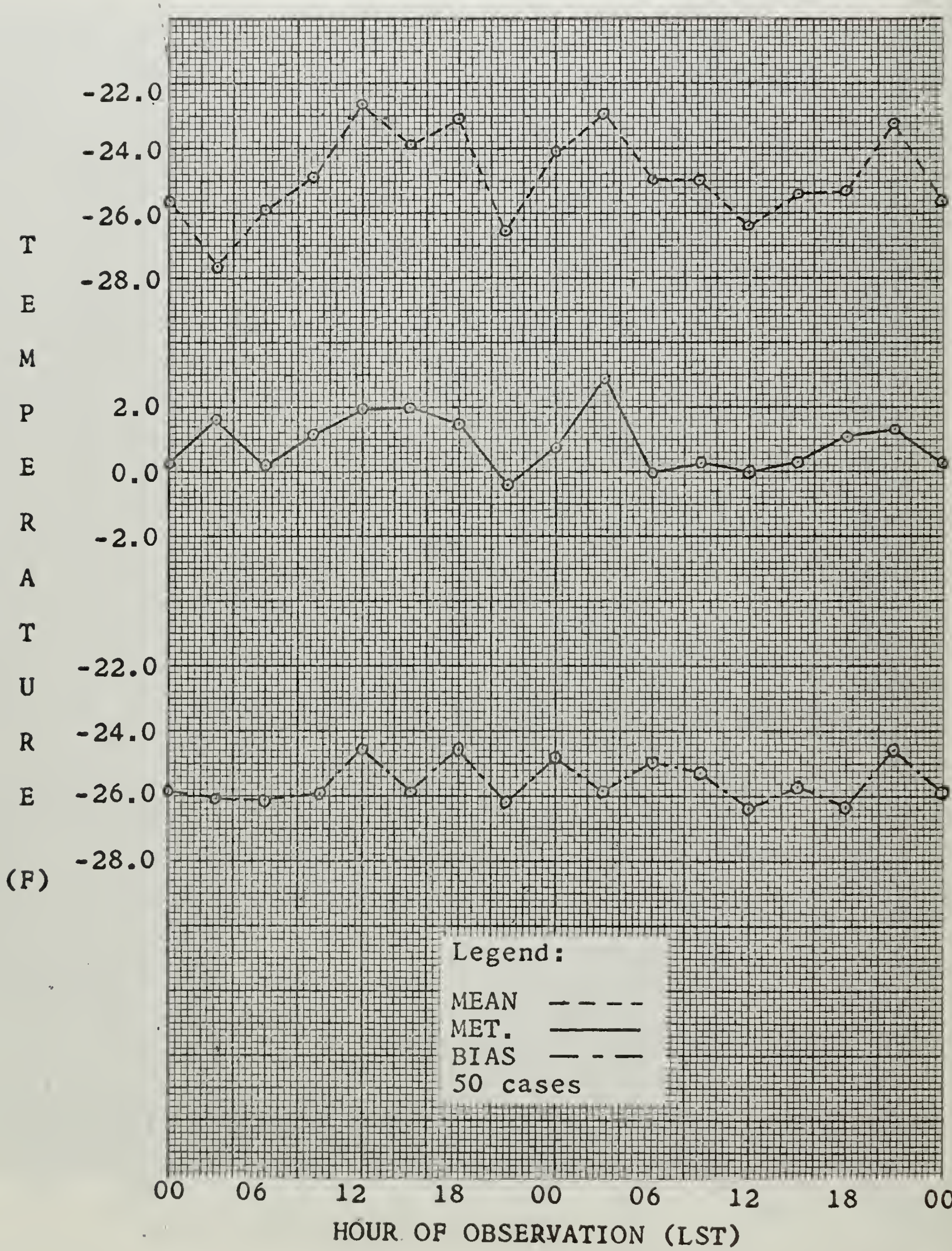


Figure 15a: Comparison of the mean 60-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

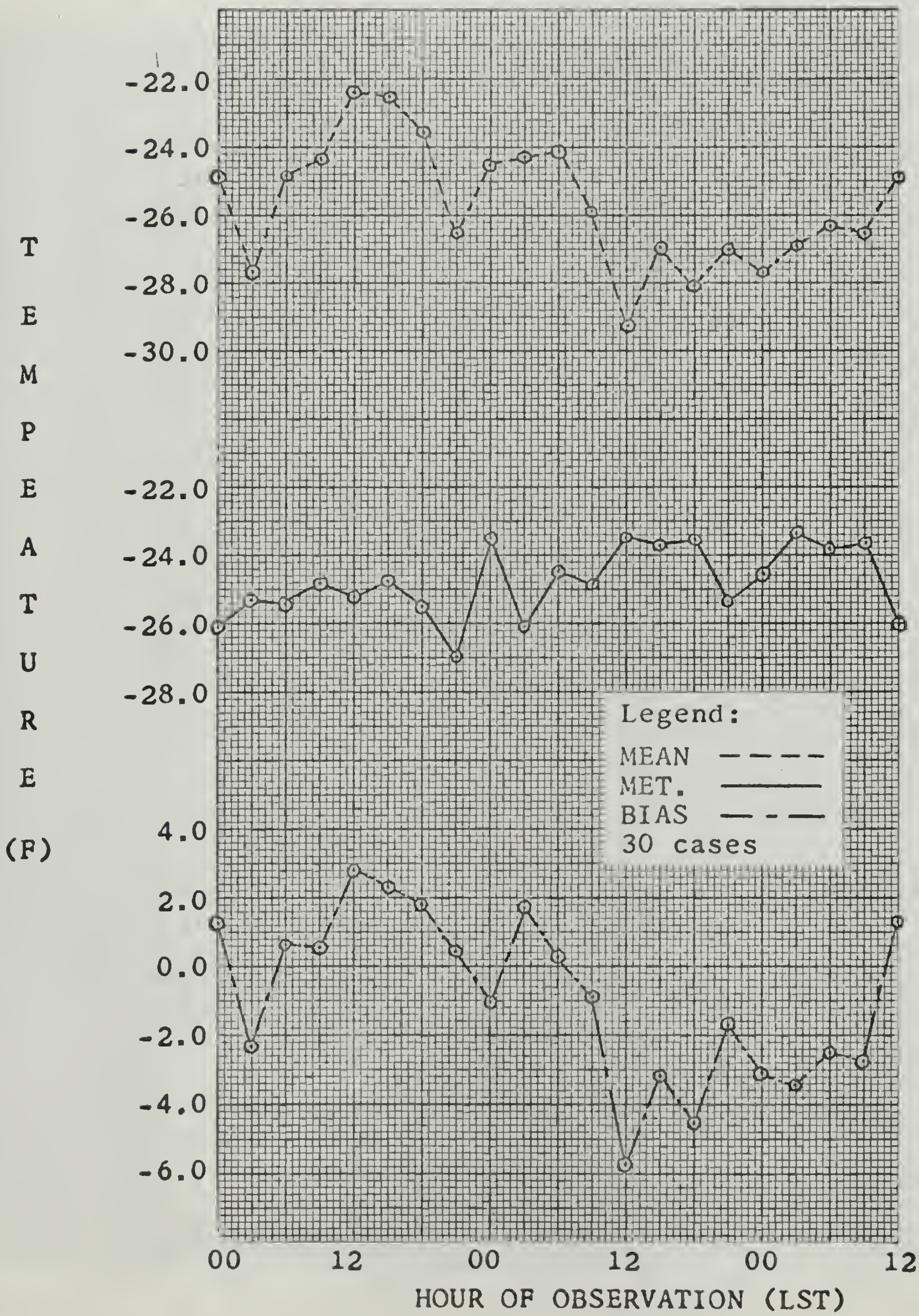


Figure 15b: Comparison of the mean 60-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤5/10)

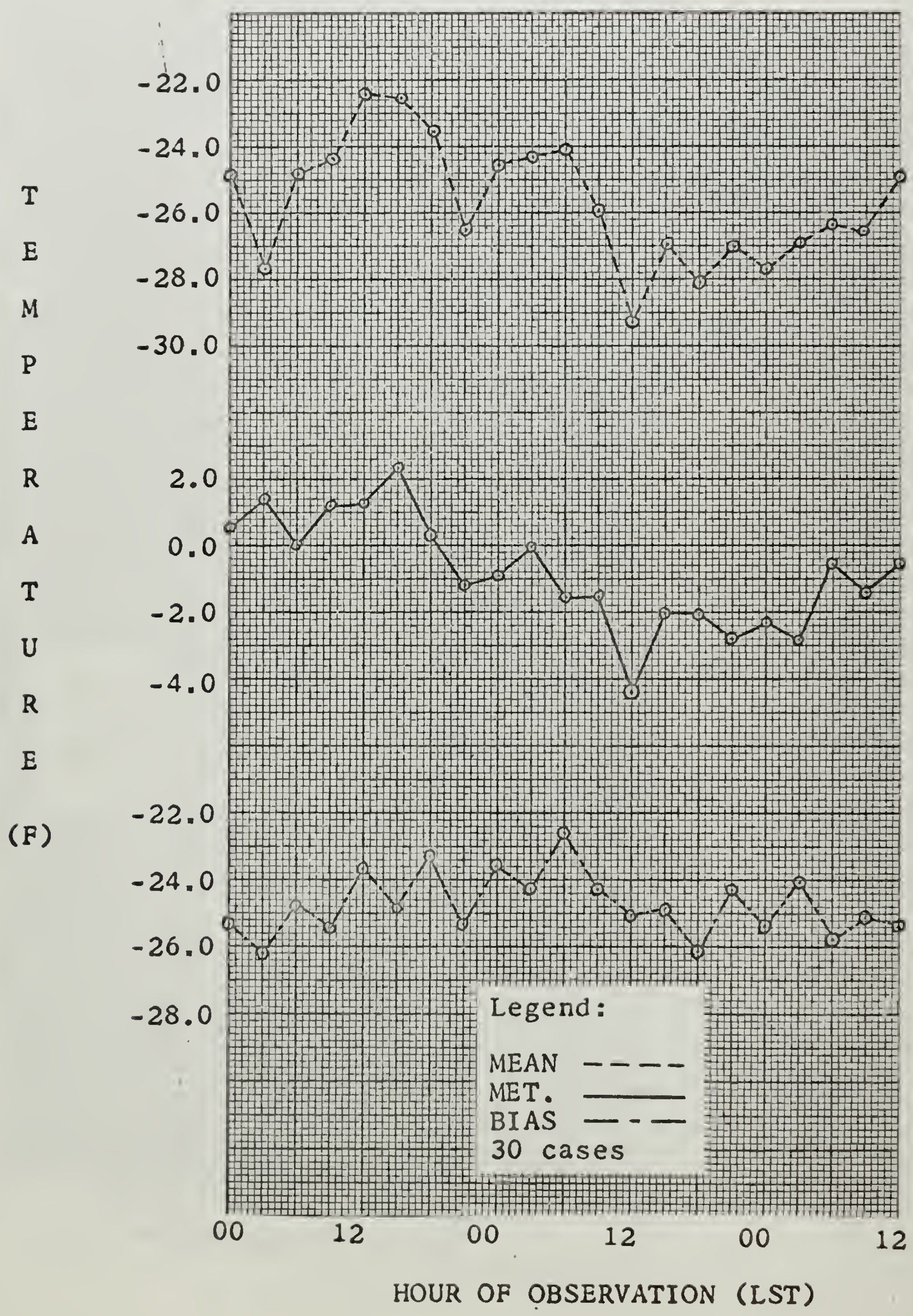


Figure 16a: Comparison of the mean 72-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

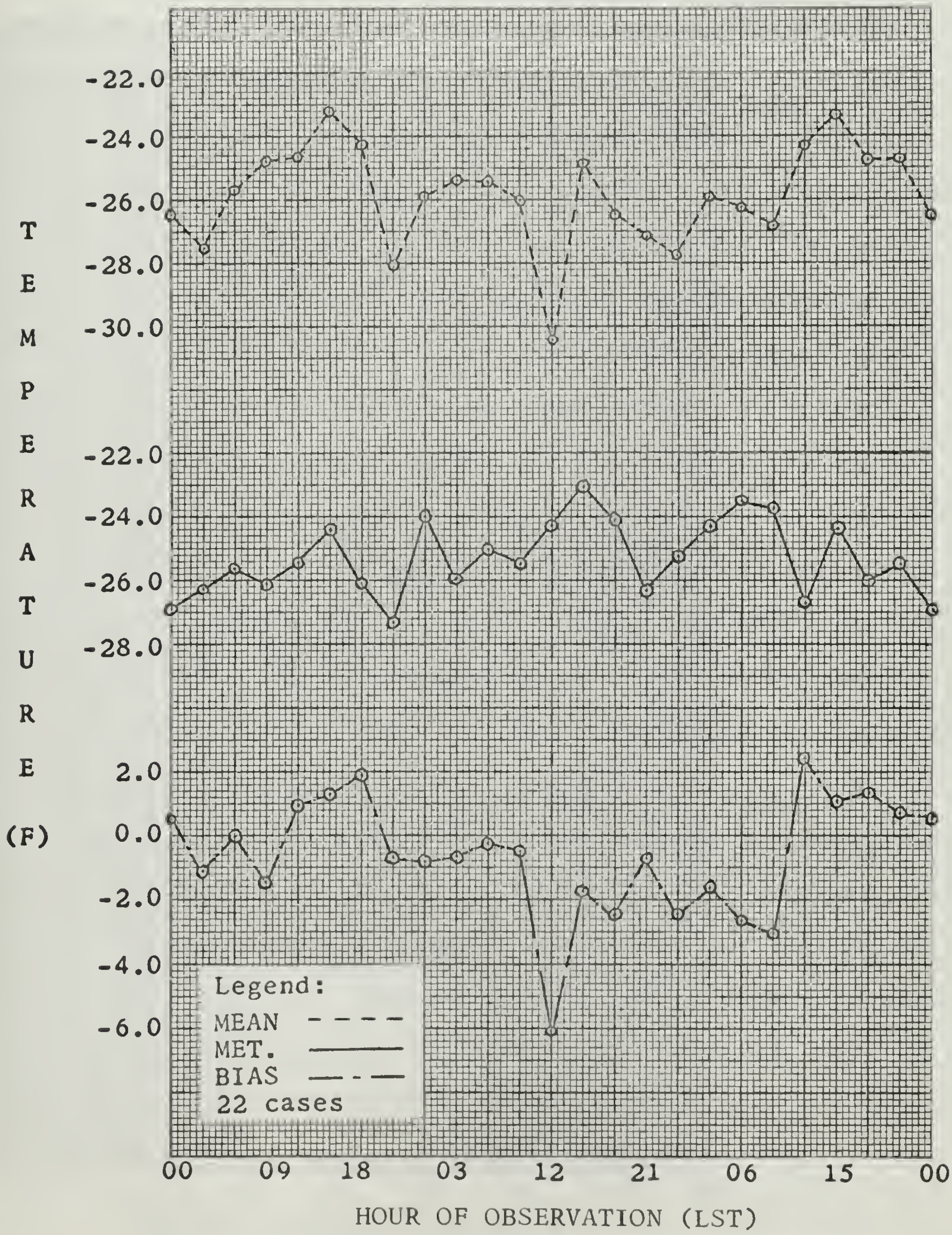
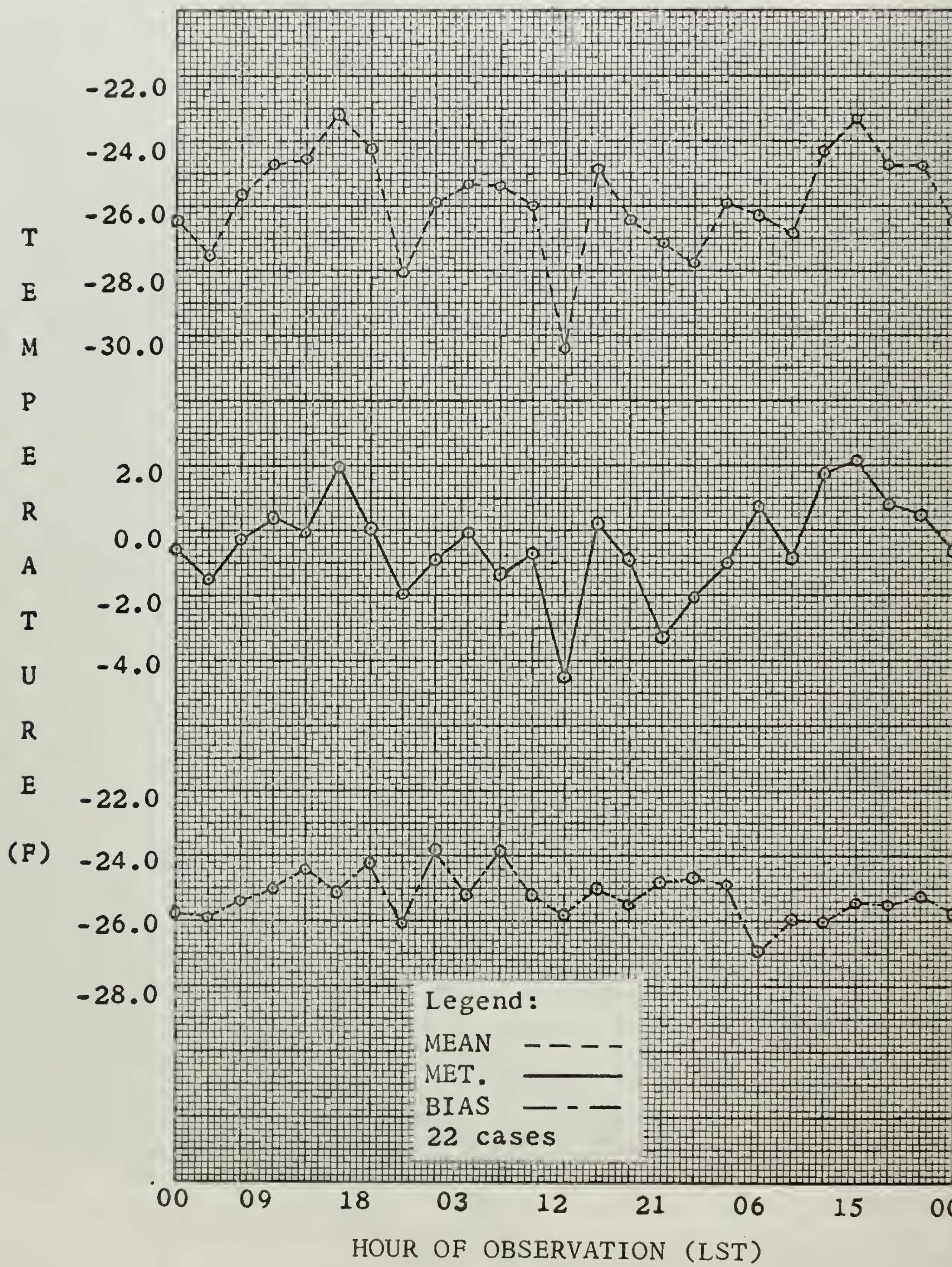


Figure 16b: Comparison of the mean 72-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)



more complex. For the 60 and 72 hour intervals, the bias curves have definite convex curvatures. It was expected that the bias curves would become less smooth as the number of qualifying periods decreased and the effects of randomness in the data increased, but the convex curvature was unexpected and is not fully understood.

An explanation may be that the periods of strongest inversion are of relatively short duration. This is not to say that the inversion is destroyed, but merely that its effectiveness is reduced by a random or cyclic increase in windspeed and/or cloudiness to values approaching the limiting values of the criteria. Increases above the criteria could, of course, occur between the times of observation. The effect of these increases may be sufficient to slow or even to temporarily reverse the otherwise longer term cooling process. A few such periods, randomly contained in the relatively few number of periods meeting the selection criteria for the longer intervals, could result in the observed bias curves.

There is little variation in the average temperature of the observed temperature curves in this set of figures. The meteorological temperature variation curves for the 24, 48 and 72 hour intervals show a tendency for a relative minimum temperature to occur at 1500. There is otherwise, very little consistency in the times of occurrence of maximum and minimum temperatures in the meteorological variation curves of the set. Therefore, no support is given to the theory of a diurnal temperature variation.

The next set of curves was computed to determine the applicability of a statistical bias effect for other than strong inversion periods and to provide the means for evaluation of the relative magnitudes of the effect of cloud and wind on the temperature inversion. It was anticipated that periods meeting the criteria of windspeeds $>$ 15 mph and cloudiness $>$ 5/10 would be non-inversion in nature and would exhibit a convex statistical bias curve. Figure 17b, however, shows it to be concave during the first half of the period and rather flat for the remainder. A possible reason for this could be a lag between the onset of winds $>$ 15 mph and cloud cover $>$ 5/10 and the destruction of the inversion. However, comparison of the mean temperature variation curve temperatures of Figures 9a and 17a show that in the present instance, the temperatures are 17 degrees warmer than, and probably thus physically removed from the inversion periods contained in Figure 9a.

Figures 18 and 19 show the results for selection criteria of all cloud amounts, but with windspeeds $\leq$ 15 mph and then $>$ 15 mph respectively. With fewer cases the statistical bias curve of Figure 18a is not as smooth as that of Figure 19b. The fact that the bias curve for windspeeds $>$ 15 mph does not have convex curvature lends support to the suggestion that cloudiness, rather than windspeed plays the dominant role in the polar night temperature fluctuations.

Figures 20 and 21 show the results for the selection criteria of all windspeeds, but with cloudiness $\leq$ 5/10 and $>$ 5/10 respectively. Comparison of the statistical bias

curves shows the marked change from concave to convex curvature as cloudiness criteria shifts from less than to greater than 5/10 coverage. This curvature change is also accompanied by a 14 degree (F) warmer mean temperature curve and the considerable radiative warming effect of increased cloud cover is again illustrated.

Four of the five meteorological temperature curves of this group of figures have a minimum temperatures at 0600 and three have maximum temperatures at 1500. In none of the figures is the range between maximum and minimum temperatures more than 0.9 degrees (F), and this is little support for implying existence of a diurnal temperature variation strongly suggested by the mean temperature variation curve of Figure 17a.

Figure 17a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed > 15 mph; cloudiness > 5/10)

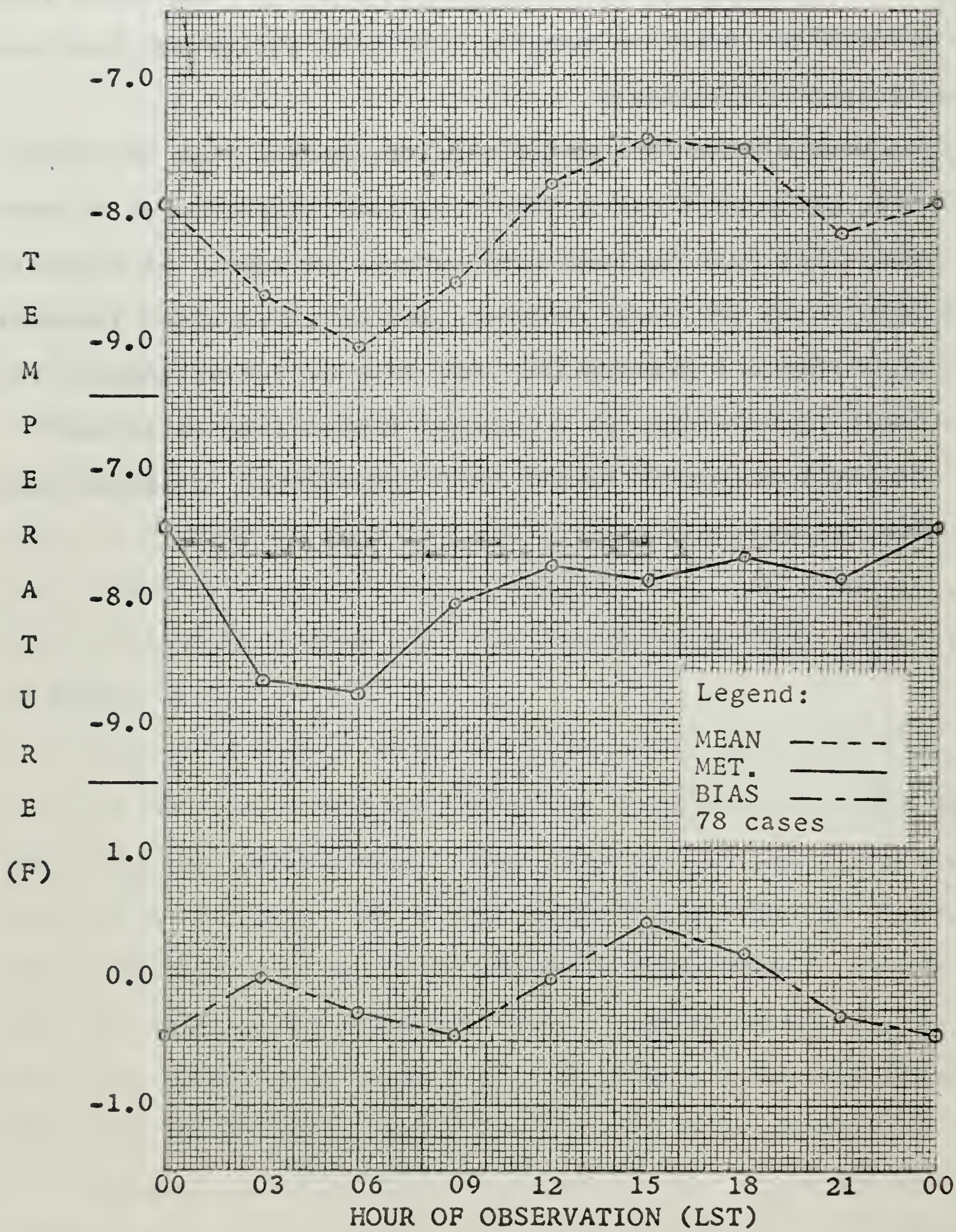


Figure 17b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed > 15 mph; cloudiness > 5/10)

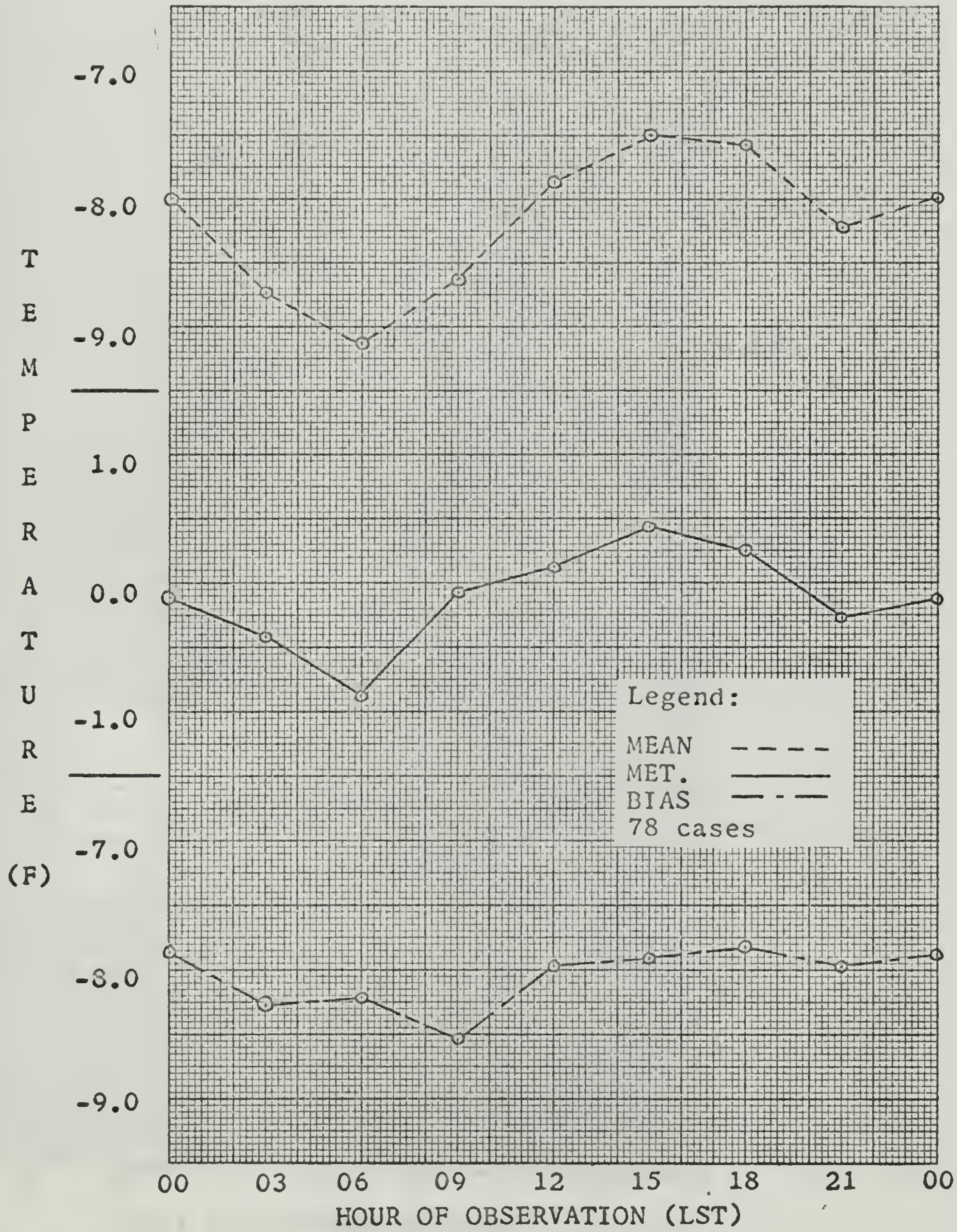


Figure 18a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed > 15 mph; all cloud amounts)

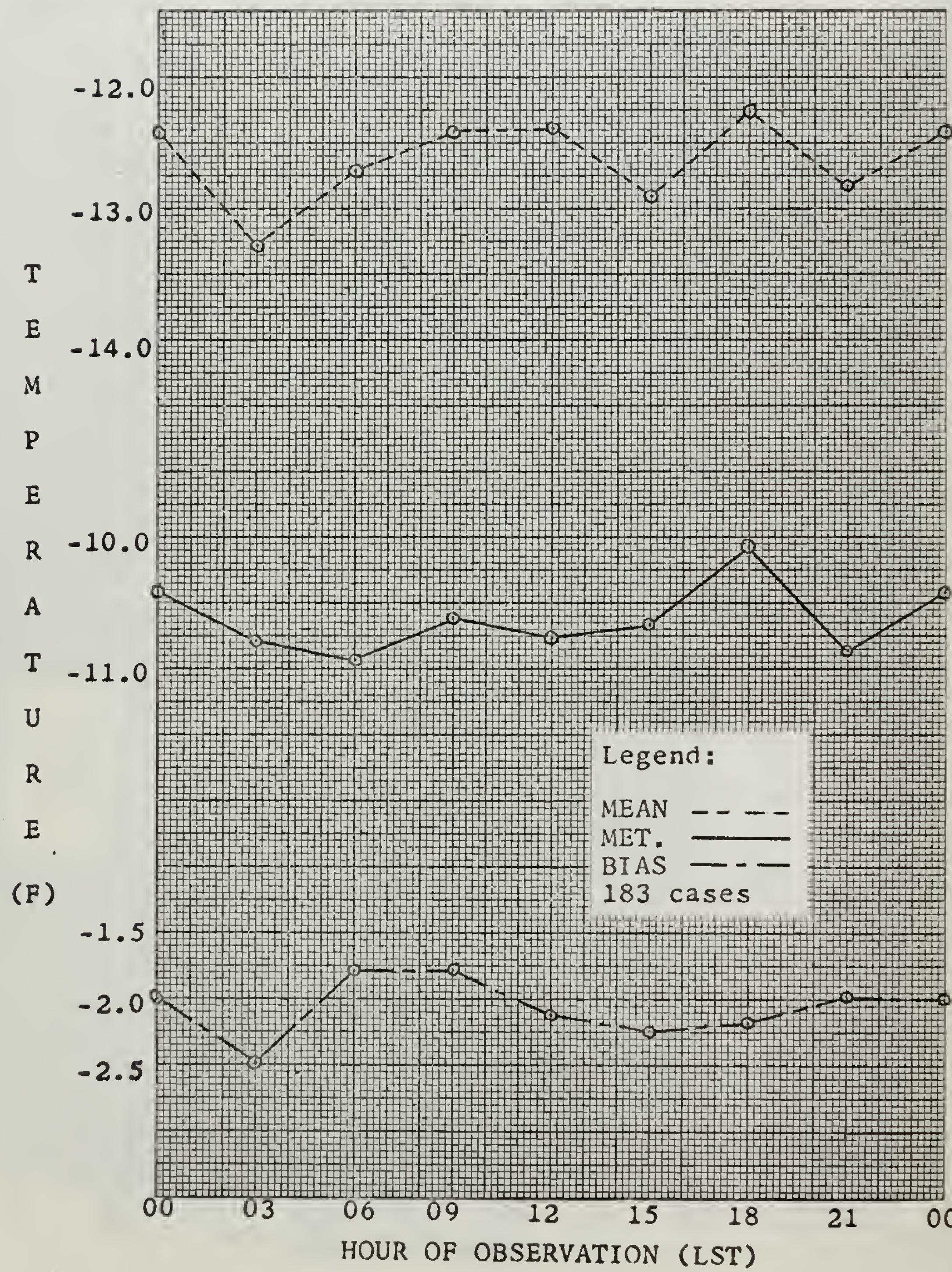


Figure 18b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and statistical bias variations at McMurdo Sound.

(wind speed > 15 mph; all cloud amounts)

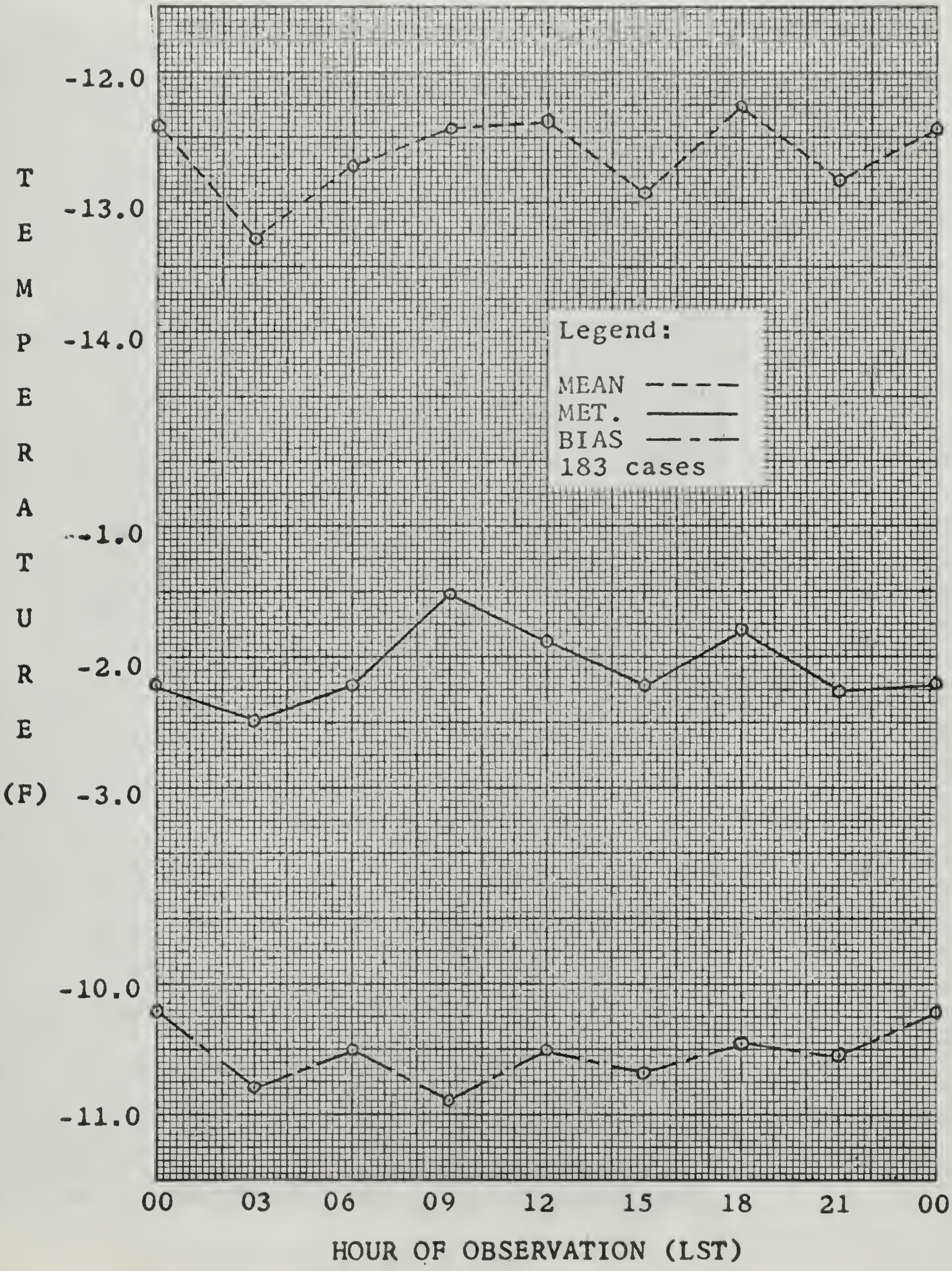


Figure 19a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; all cloud amounts)

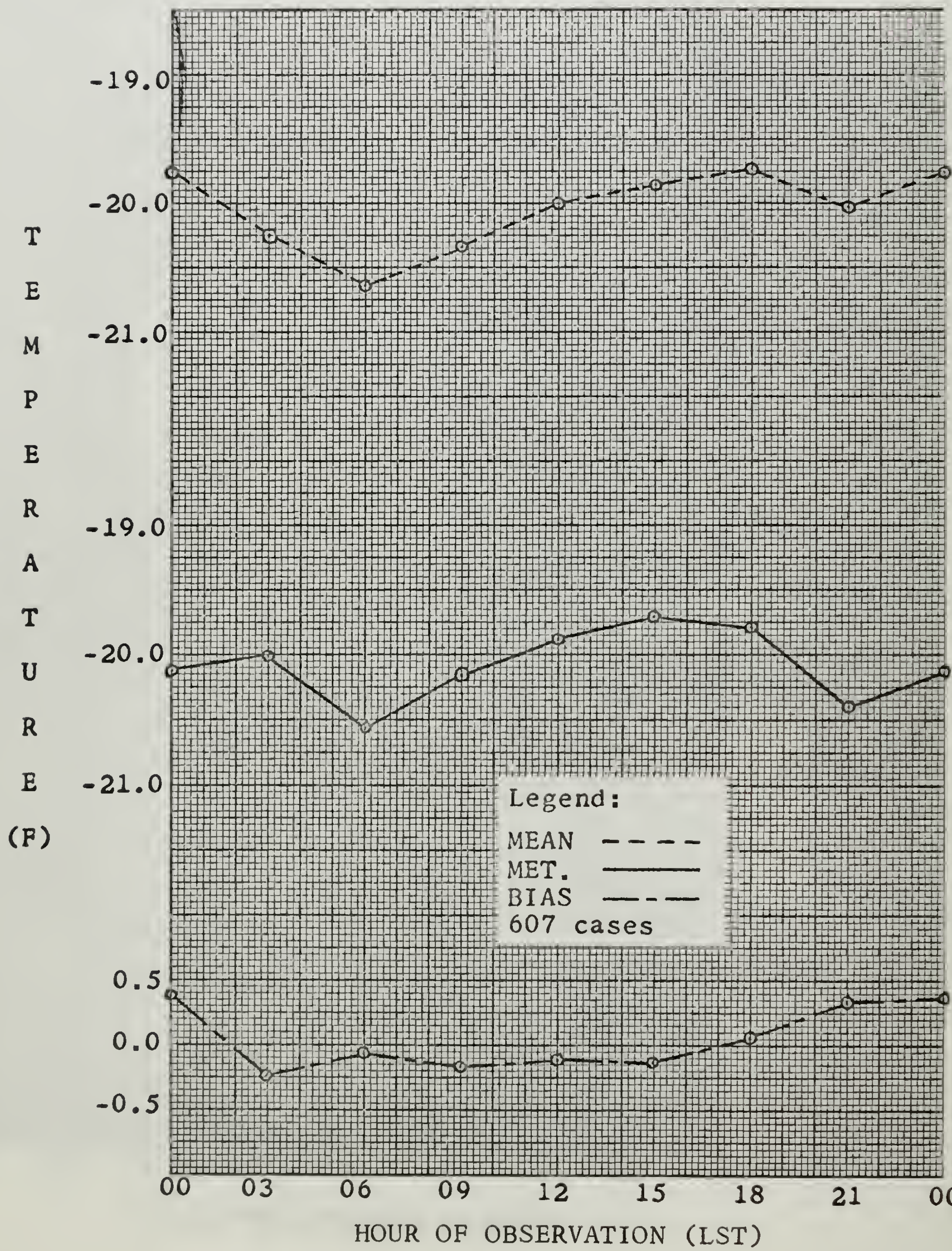


Figure 19b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(wind speed ≤ 15 mph; all cloud amounts)

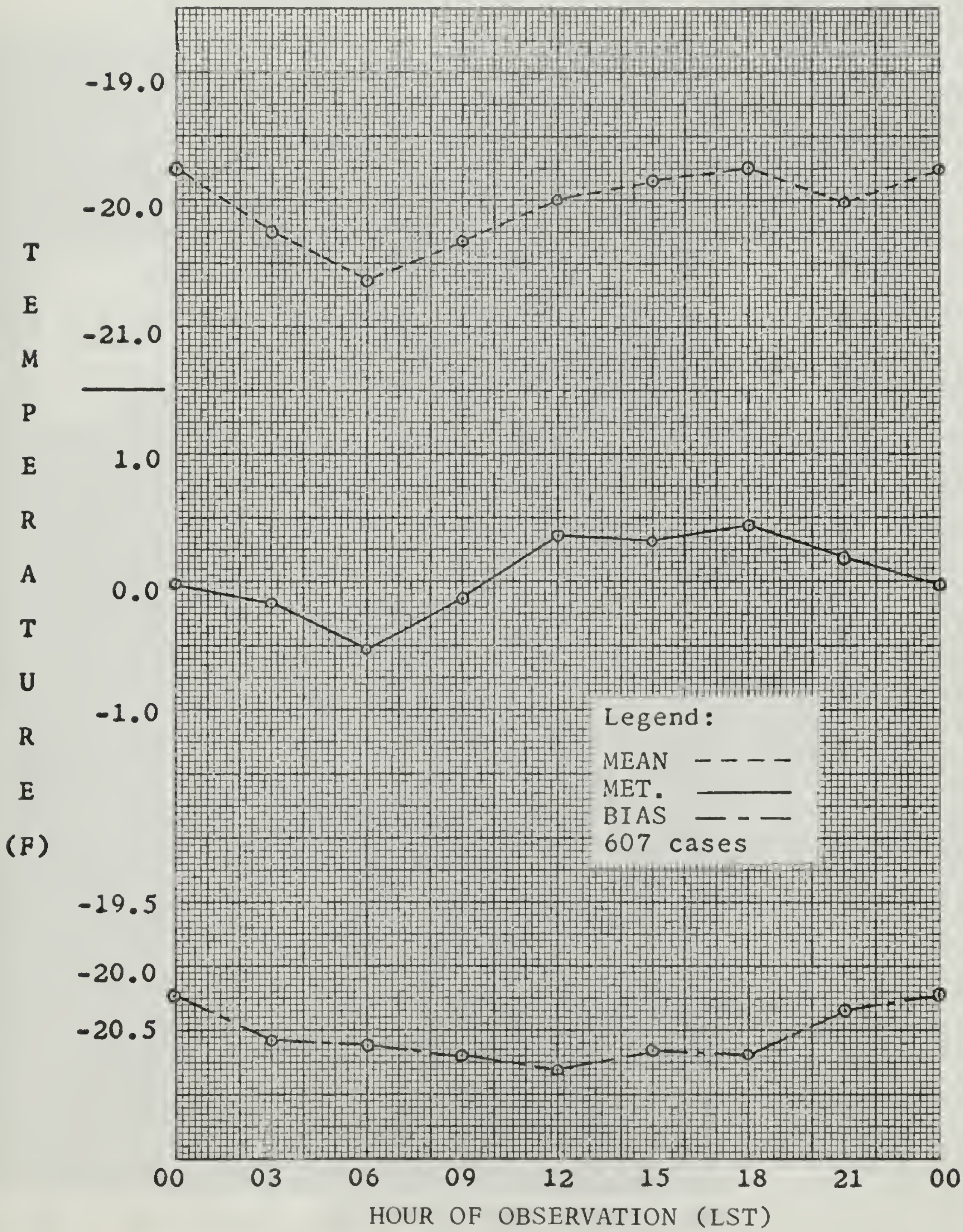


Figure 20a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(all wind speeds; cloudiness ≤ 5/10)

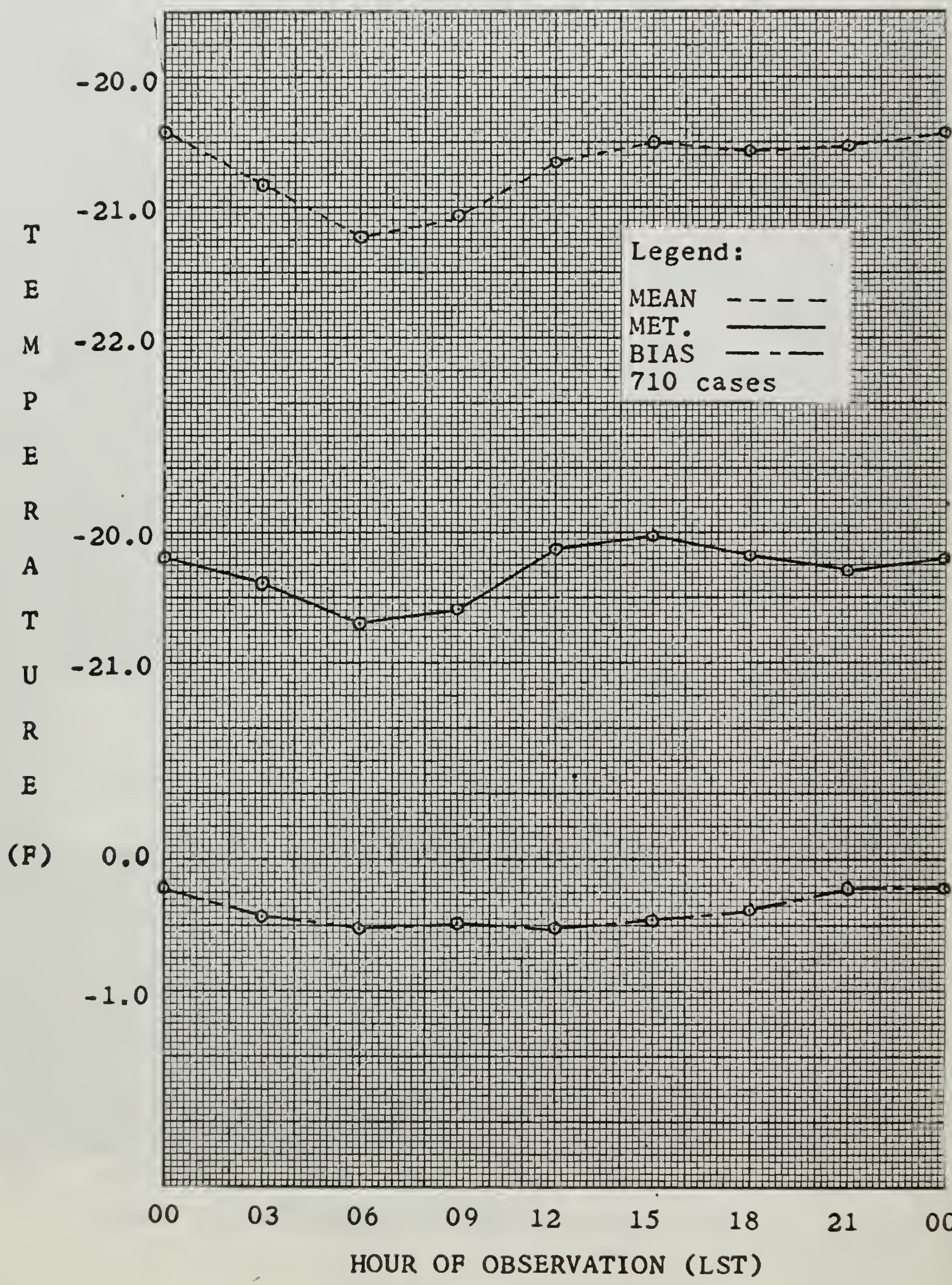


Figure 20b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at McMurdo Sound.

(all wind speeds; cloudiness ≤ 5/10)

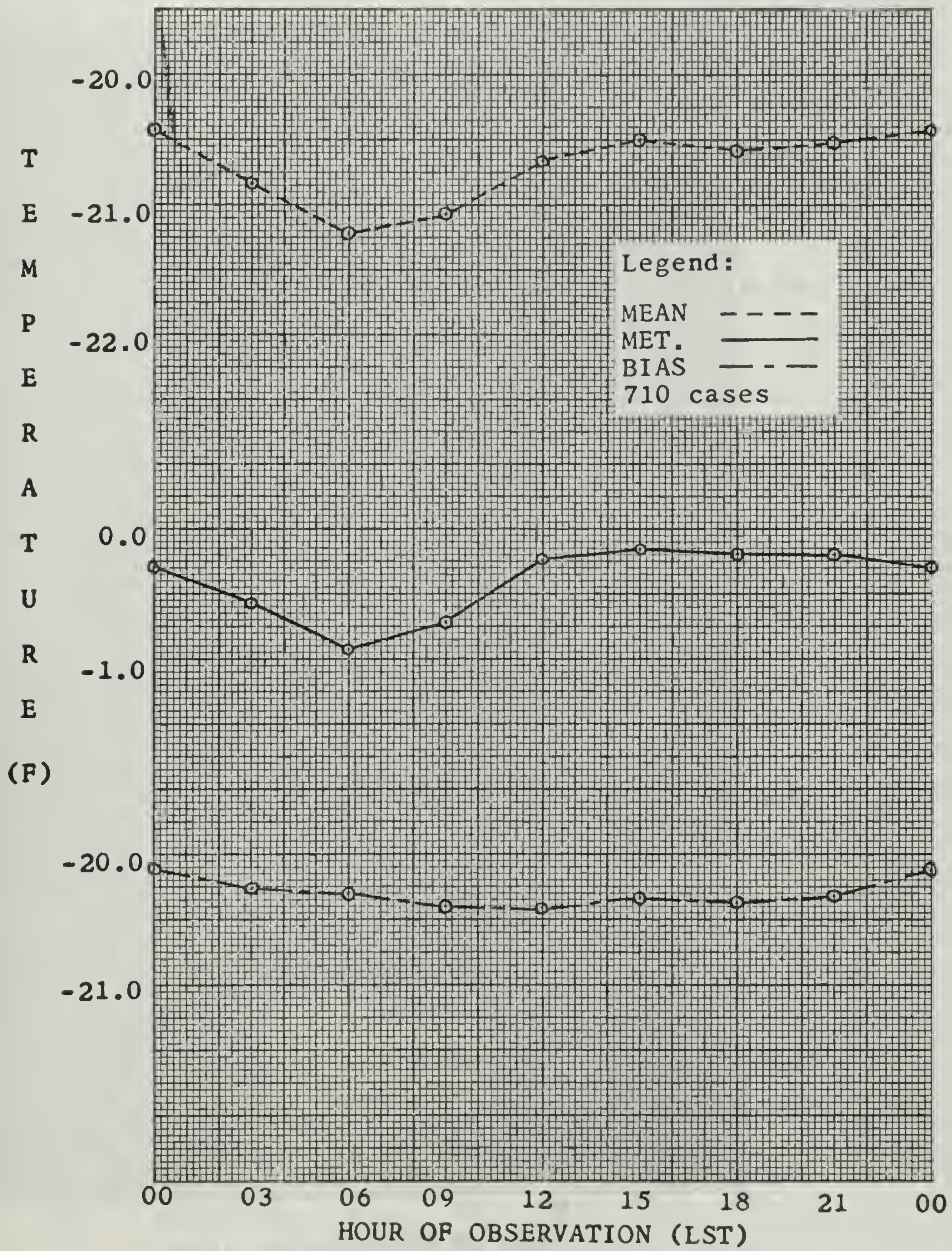


Figure 21a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(all wind speeds; cloudiness > 5/10)

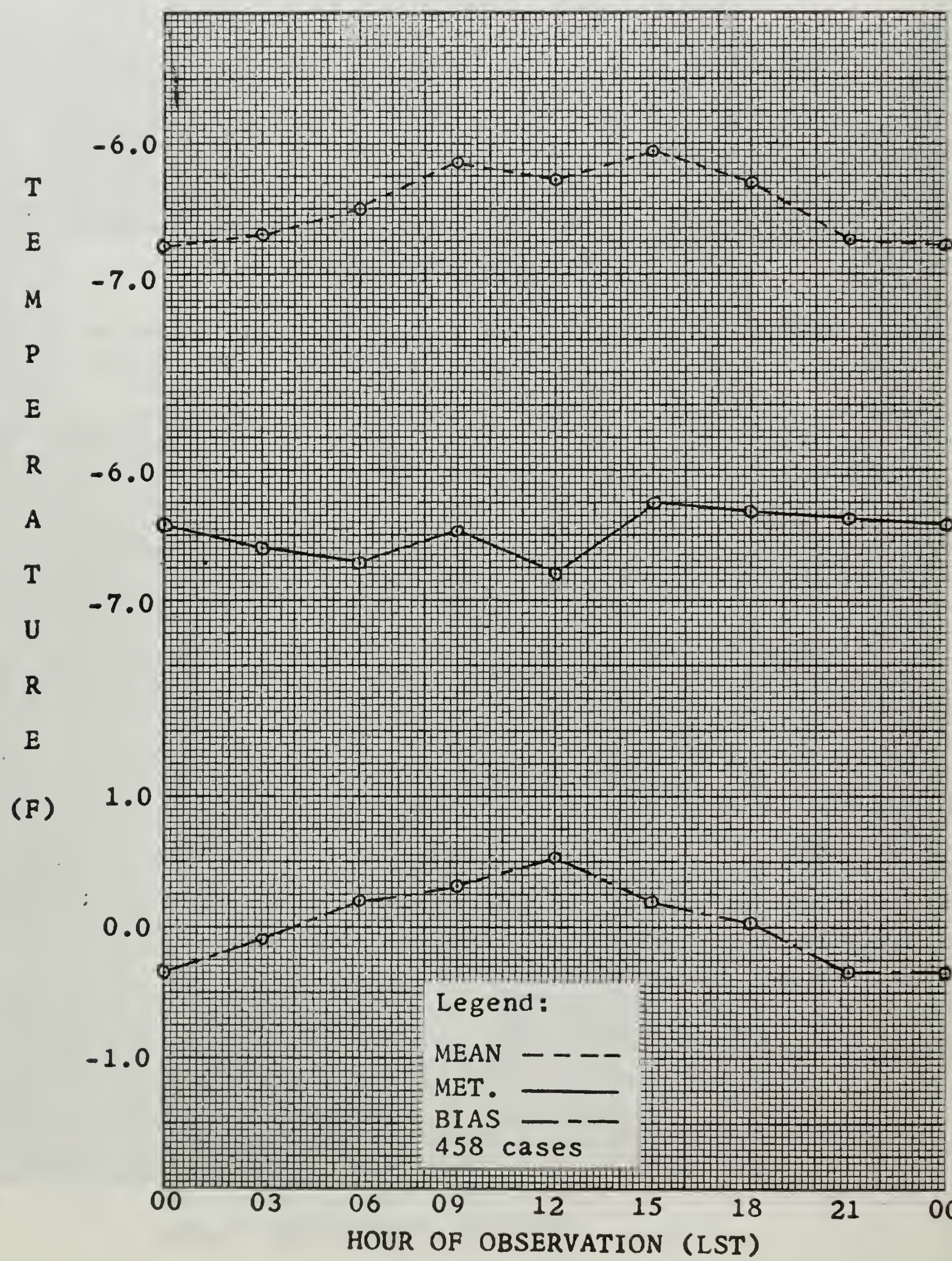
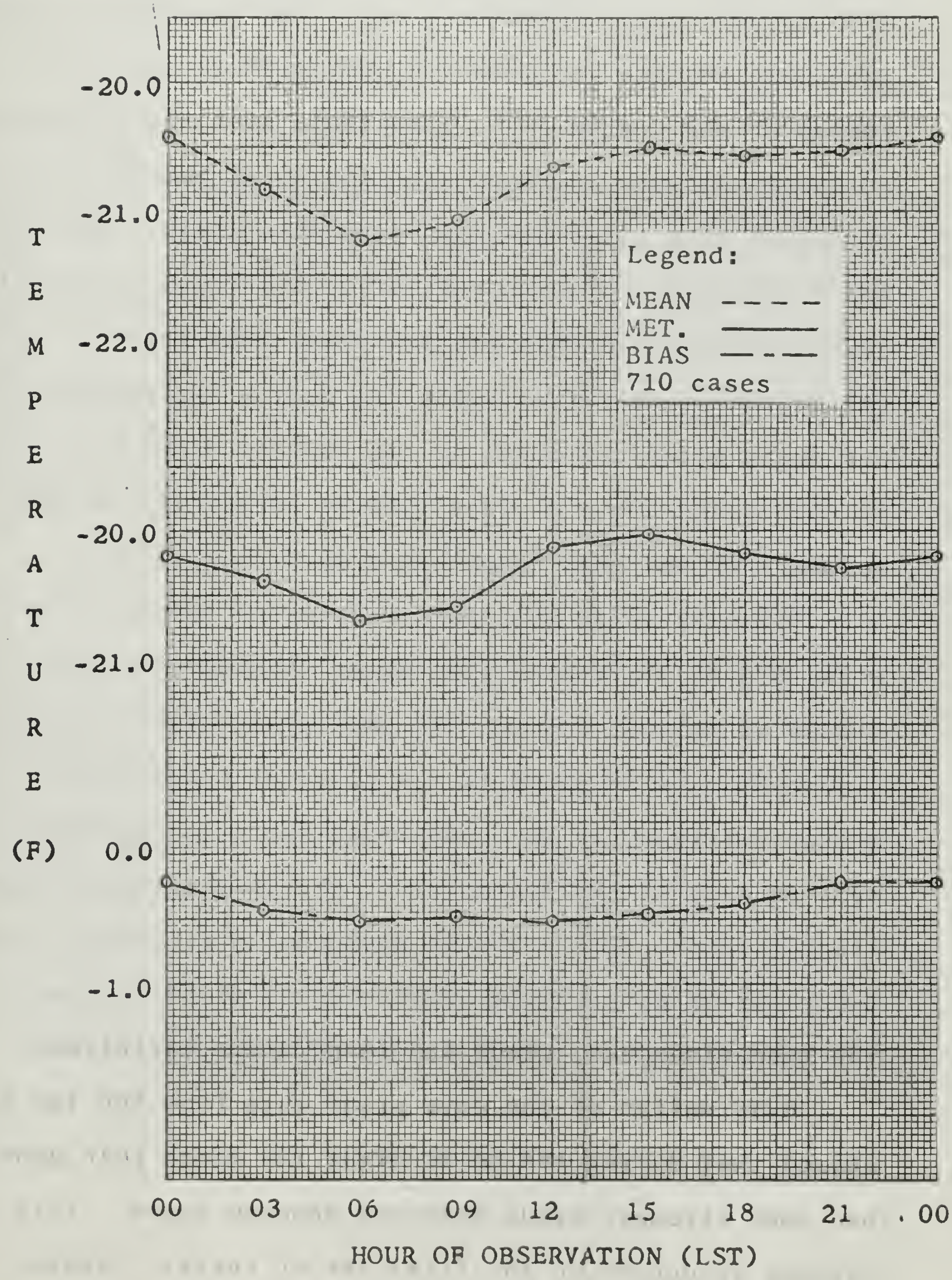


Figure 21b: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at McMurdo Sound.

(all wind speeds; cloudiness ≤ 5/10)



8. Results of South Pole Data.

Figure 22 is the polar night mean daily temperature variation at the South Pole, averaged over all consecutive 0000 to 2400 days for seven years. Two temperature scales are shown and the variation is just slightly more than two tenths of one degree (F). Only those days having all eight observations were averaged and because of the missing data, 64 out of a possible 736 days were eliminated. The remaining 672 periods on which the curves are based are sufficient number on which to base the statement that there is no normal diurnal temperature variation during the polar night at the South Pole. In light of the McMurdo Sound discussion, an increased number of cases should serve only to reduce the varience of the mean temperature variation curve.

The mean daily seasonal temperature trend at the South Pole, Figure 23, showed even wider fluctuations than evidenced at McMurdo Sound. The same considerable aperiodic fluctuations were noted on the computer print-outs of the seasonal trends for the individual years during this coldest time of year at the South Pole. The temperature fluctuations are thus quite active and it would be interesting to modify the computer programs to provide for a direct comparison of the mean windspeed, cloud and temperature variations.

Examination of the data print-outs from the two stations showed that during the polar night the South Pole generally had much stronger winds than did McMurdo Sound. This is further evidenced in the first set of curves, Figures 24

Figure 23

Mean temperature variation at the South Pole averaged for all days during the polar night for the years 1957-1964. Two temperature scales are illustrated.

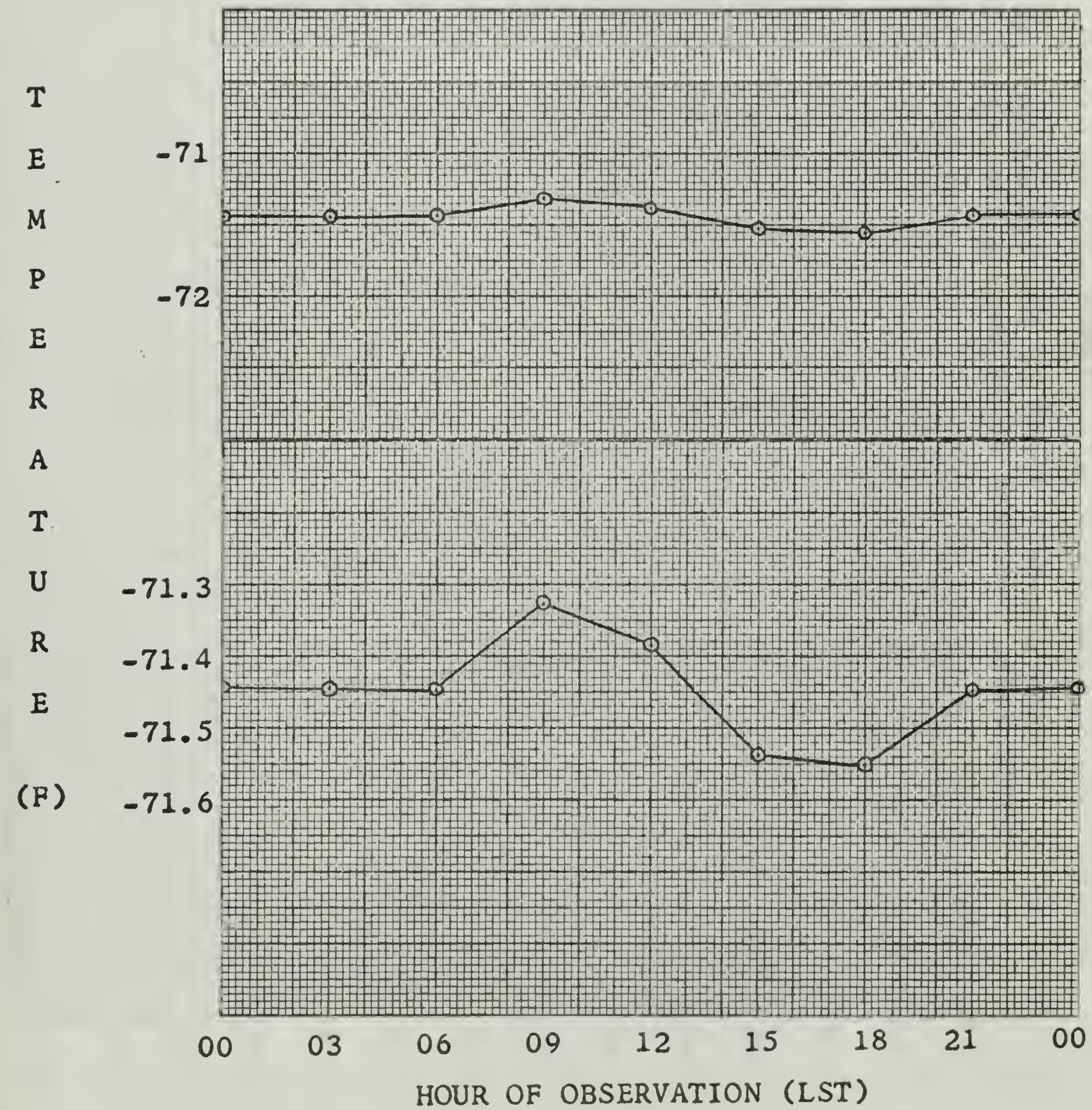
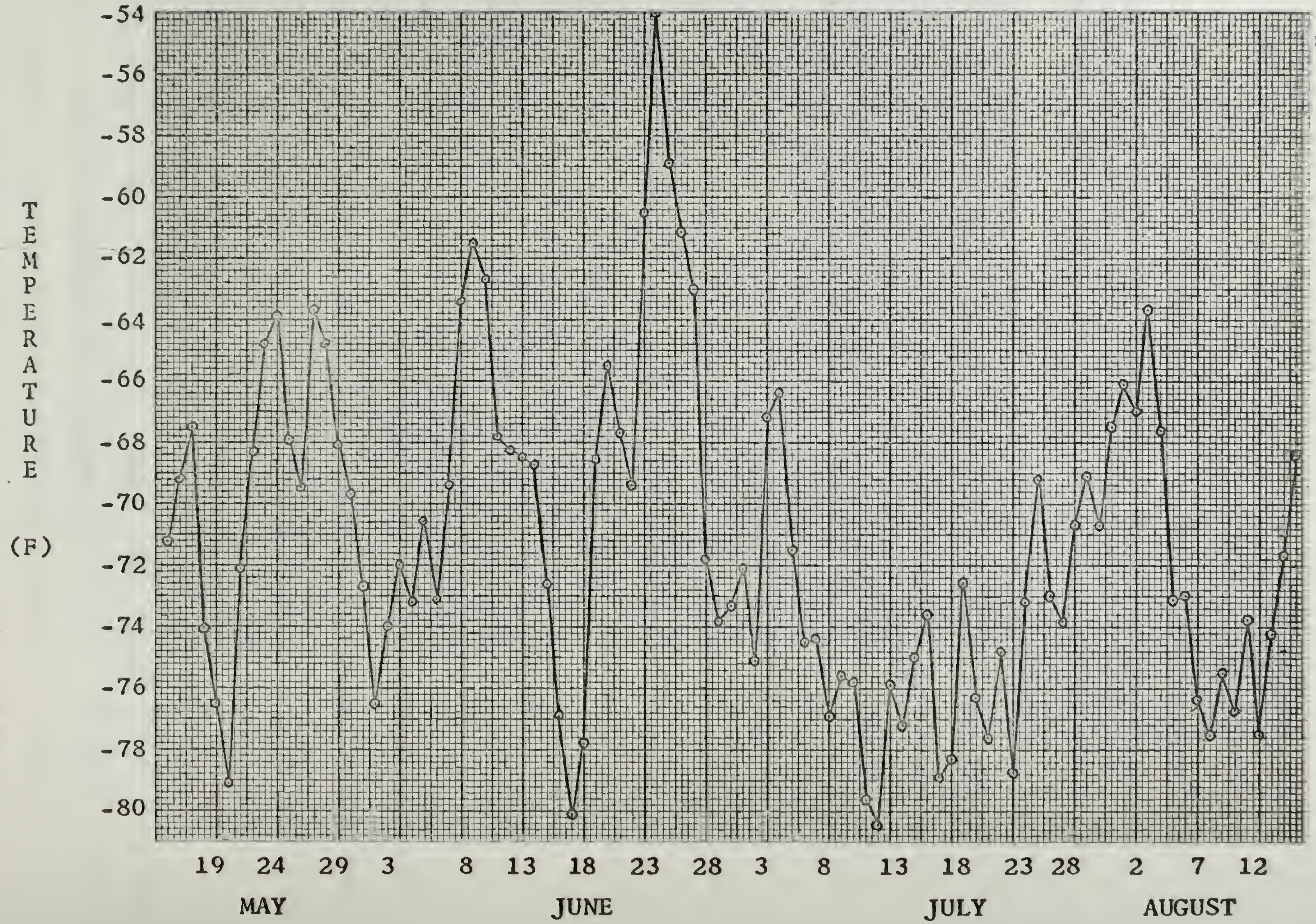


Figure 23

Mean seasonal trend of the temperature at the South Pole, averaged daily during the period 1957-1964



through 27 for which were selected 24-hour periods with cloudiness $\leq$ 5/10 and with windspeeds increasing from 10 to 15 to 20 to 30 mph, respectively. Table 6 shows how the number of periods meeting the selection criteria increased from 20 to 1217 as the minimum windspeed requirement was raised. The few periods having windspeeds $\leq$ 10 mph makes the representativeness of the curves of Figure 24 suspect, although smoothing indicates that the statistical bias curve is concave. The statistical bias curves of the remaining figures are markedly concave as expected and it appears that windspeeds $\leq$ 20 mph and cloudiness $\leq$ 5/10 provide optimum criteria for the selection of 24-hour inversion periods at the South Pole during the polar night. It is noted, however, that as the windspeeds are increased, the average values of the mean temperature curves also increase so that with cloudiness $\leq$ 5/10, the periods of strongest inversion are those with the least amounts of wind.

The mean temperature curves of Figures 25, 26, and 27 are noted to be dominantly influenced by statistical bias curves. The meteorological temperature variation curves of these three figures all have relative minimums at 0300 and tend toward maximum temperatures at the beginning, middle, and ends of the period. However, since the periods selected accumulate from the succeeding figures and since the range between maximum and minimum temperatures is one-half degree (F) at most, there is no basis for assuming a diurnal temperature variation for these selected days.

Figure 24a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 10 mph; cloudiness ≤ 5/10)

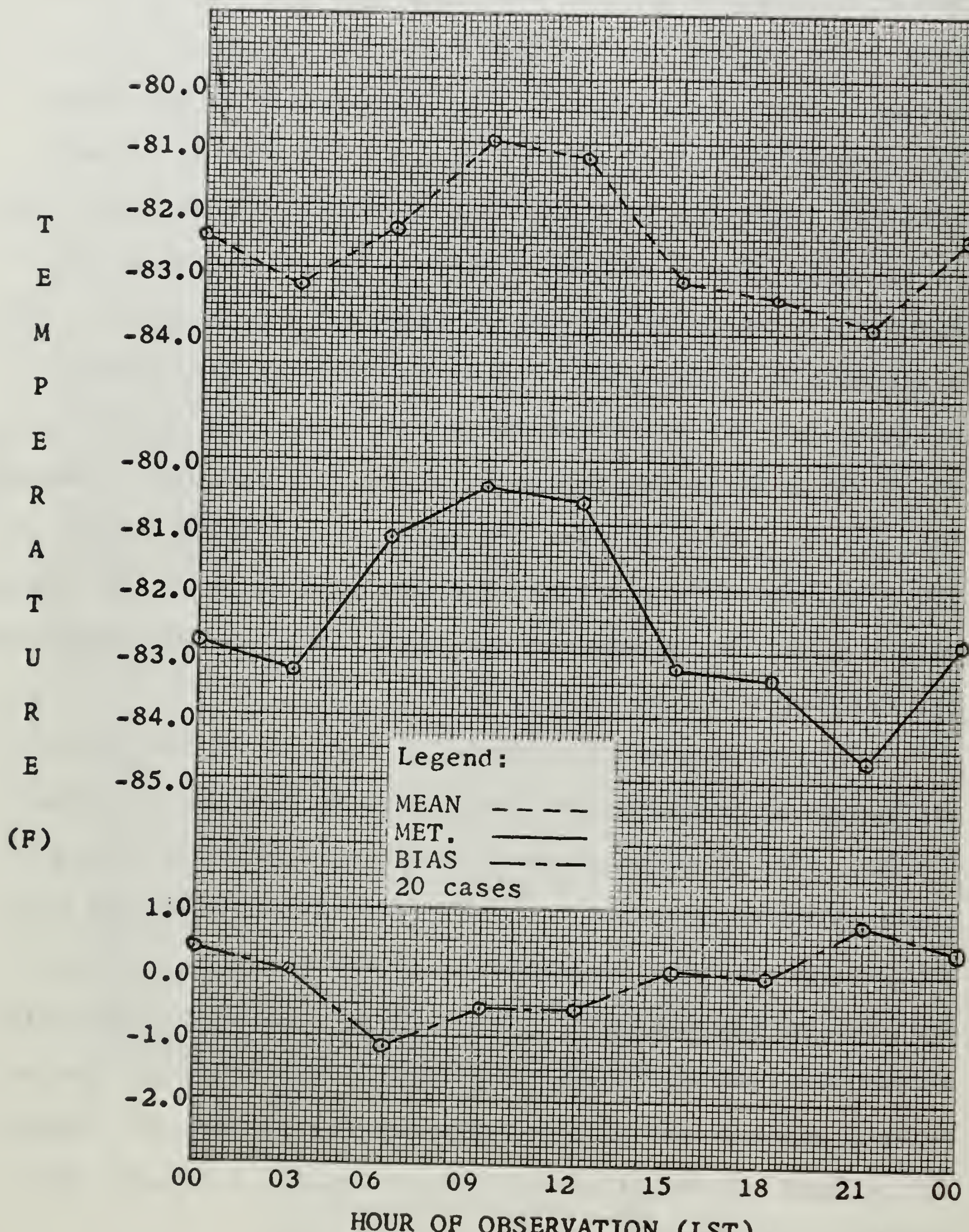


Figure 24b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 10 mph; cloudiness ≤ 5/10)

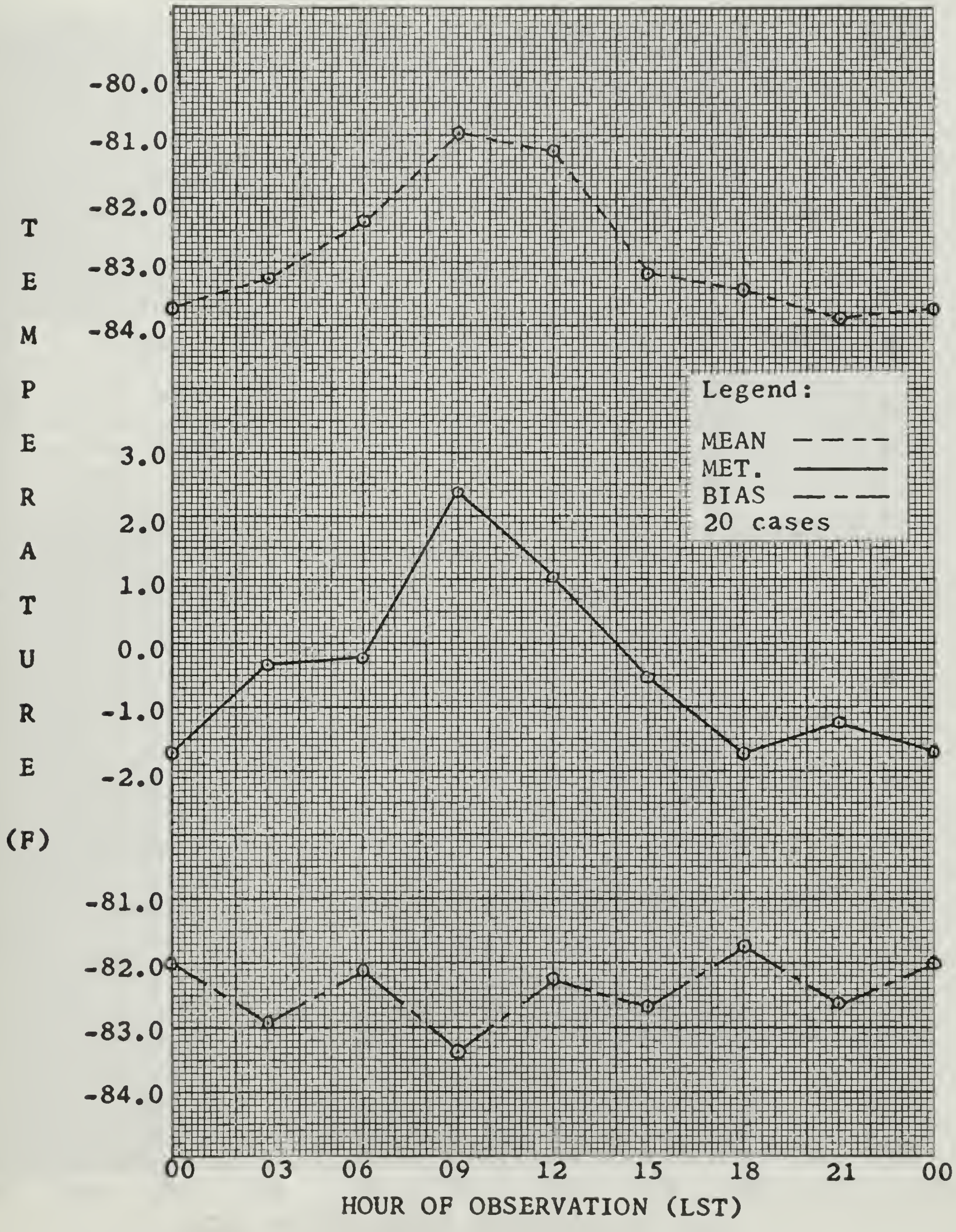


Figure 25a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

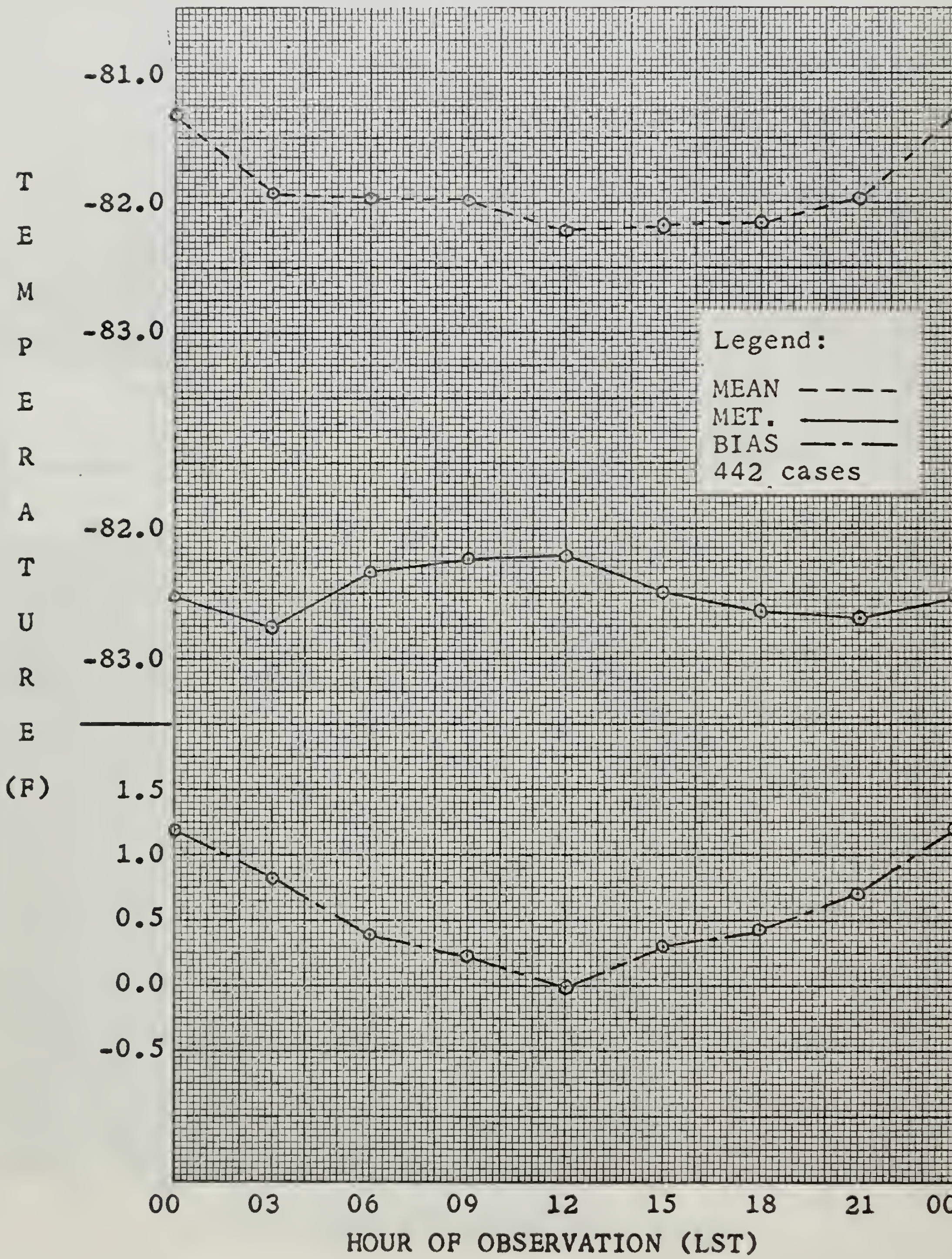


Figure 25b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 15 mph; cloudiness ≤ 5/10)

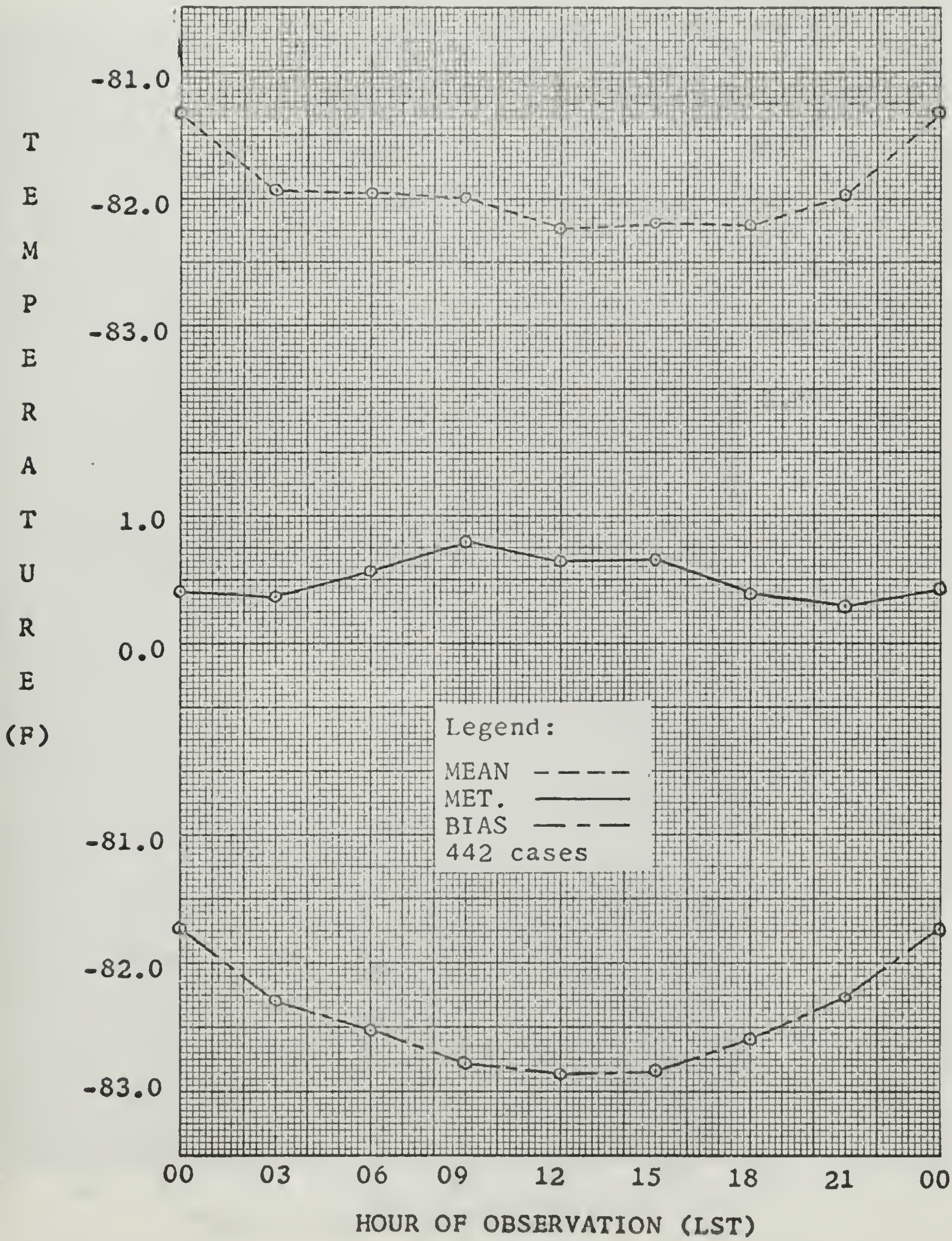


Figure 26a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 20; cloudiness ≤ 5/10)

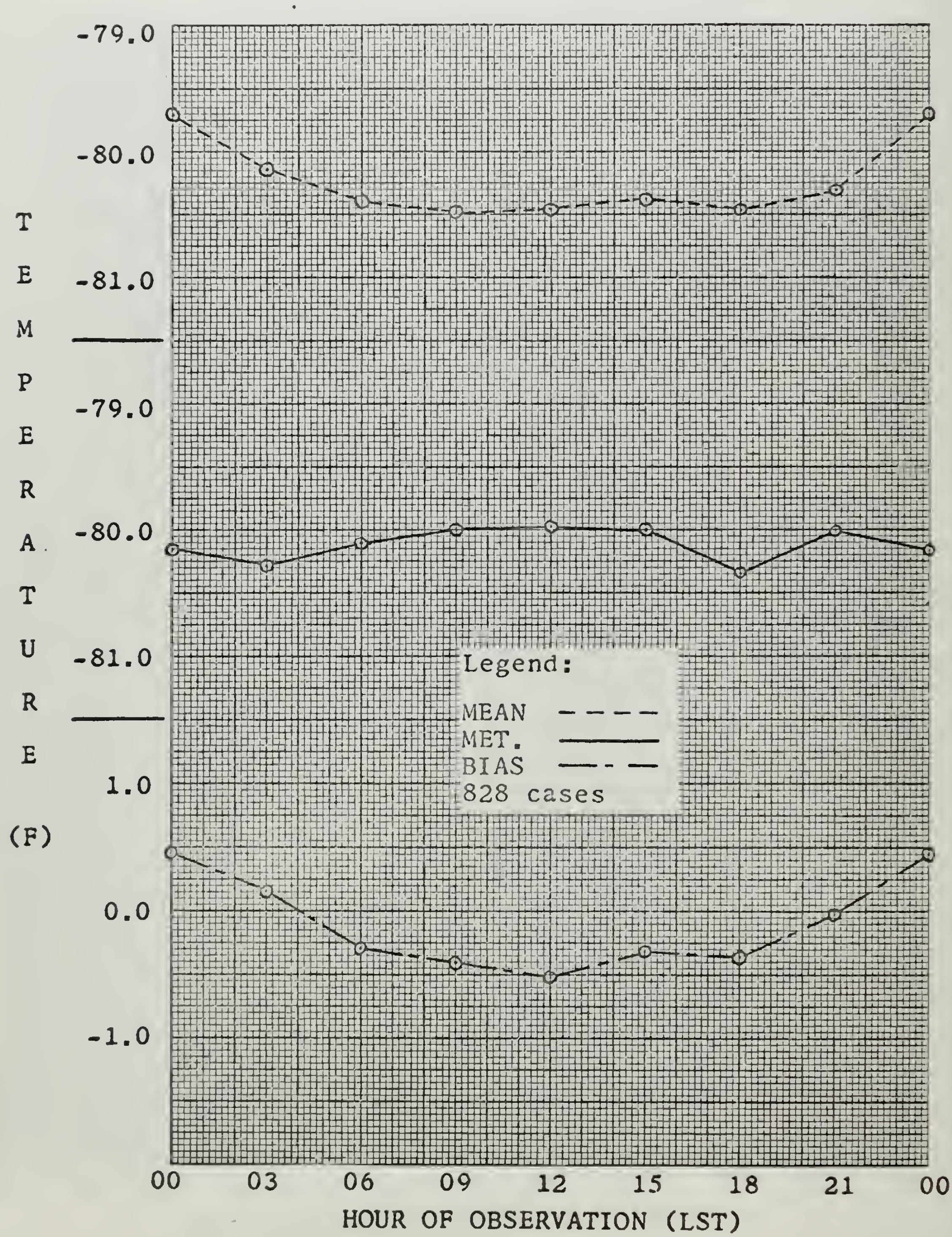


Figure 26b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 20 mph; cloudiness ≤ 5/10)

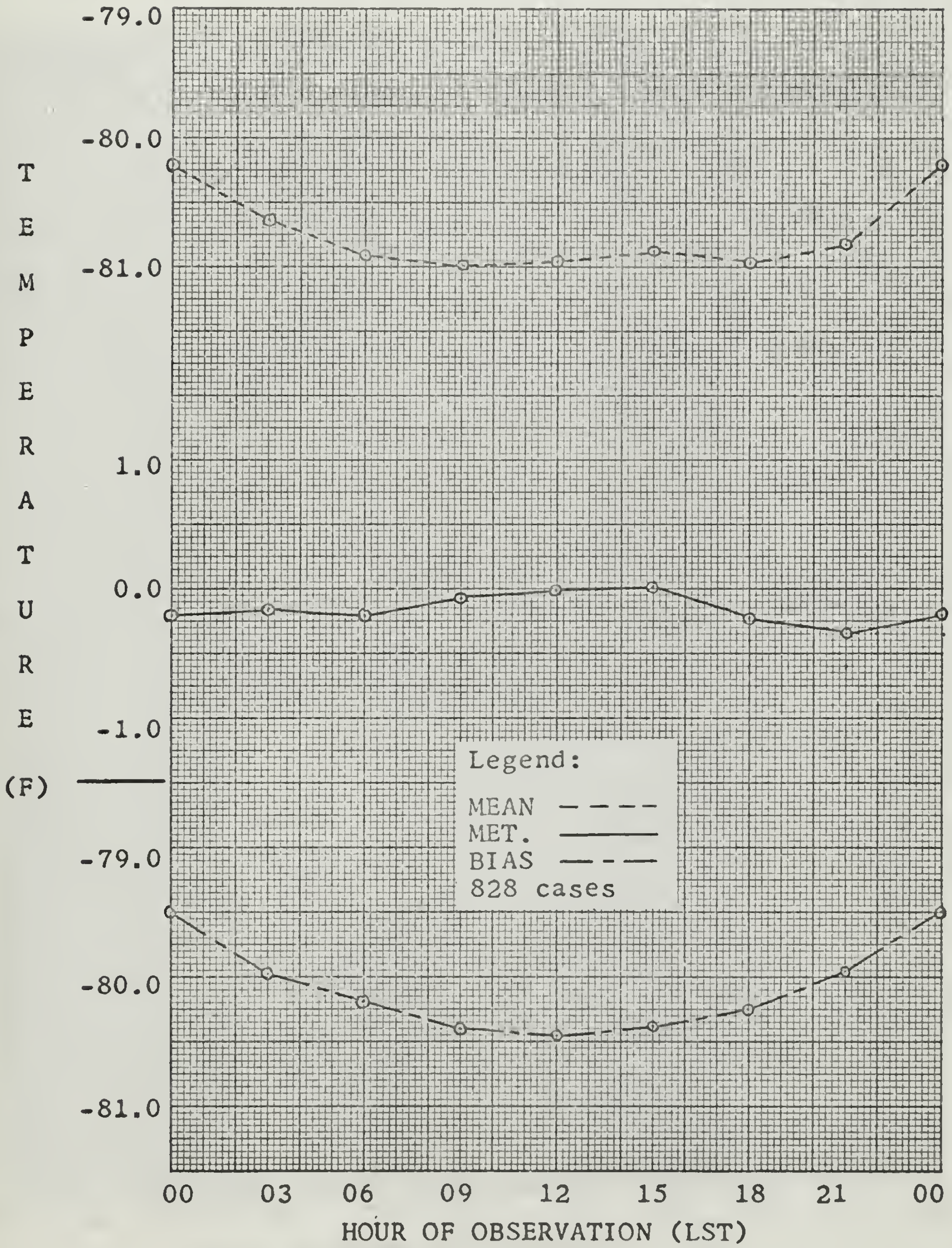


Figure 27a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed ≤ 30 mph; cloudiness ≤ 5/10)

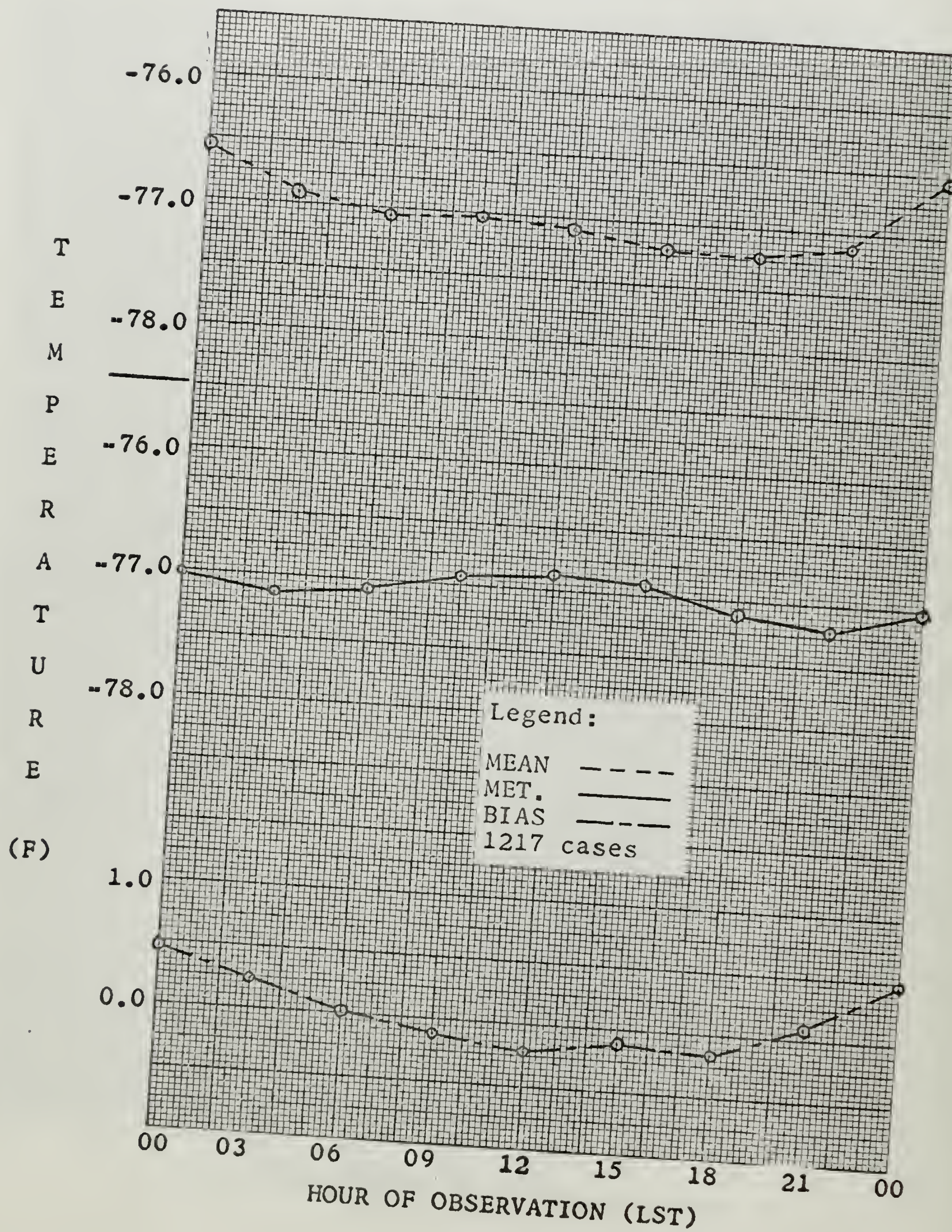


Figure 27b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed $\leq$ 30 mph; cloudiness $\leq$ 5/10)

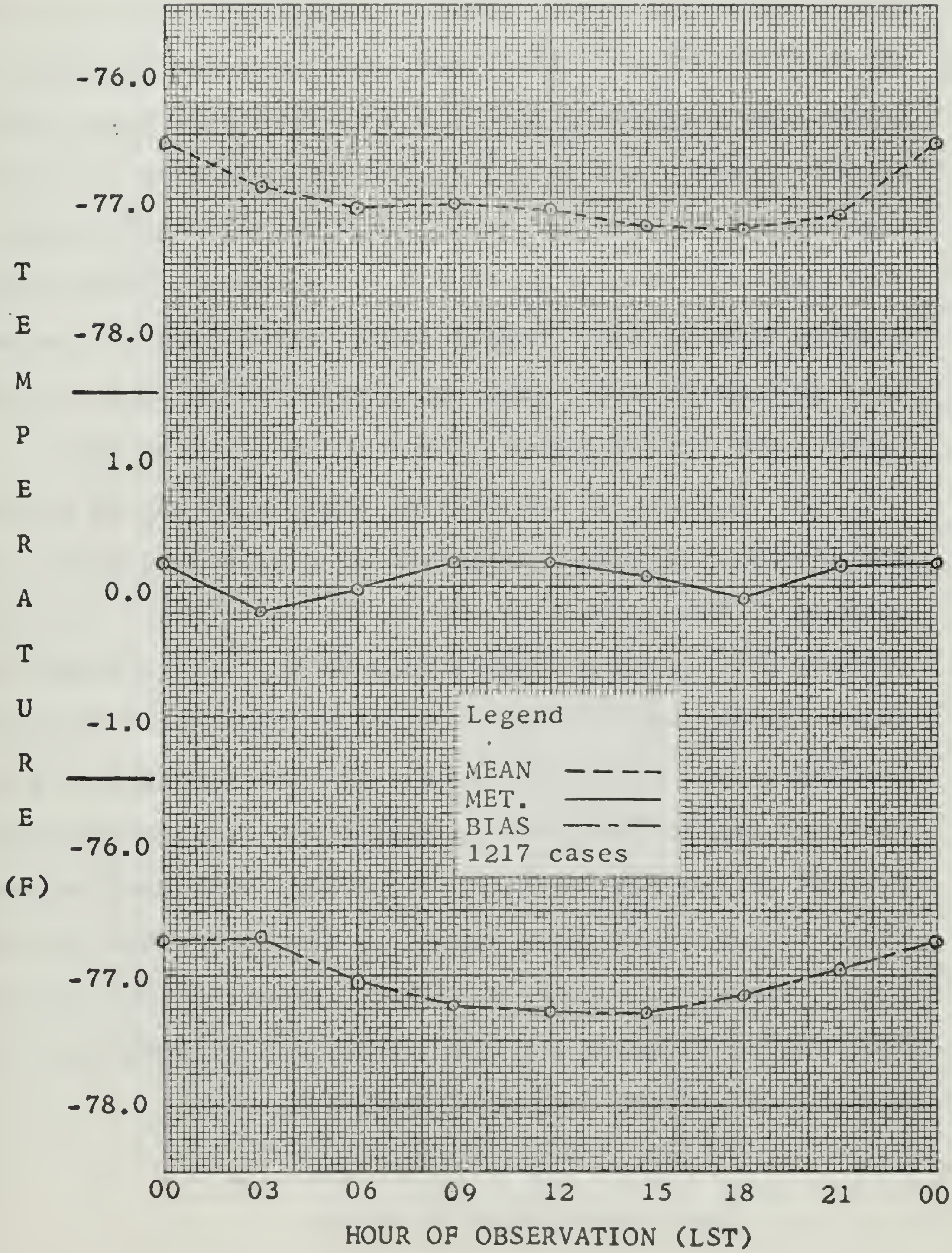


Figure 28 shows the results of selecting the 24-hour intervals with windspeeds > 15 mph and cloudiness > 5/10. The statistical bias curve is convex with a range of 2.5 degrees (F). The number of periods selected has dropped to 86, but the bias curve is quite smooth and typical of that expected for non-inversion periods. As noted previously the South Pole windspeeds were found to be higher than those at McMurdo Sound. But in trying various selection criteria it was found that with no restrictions on the cloud amount, there were no 24-hour periods with windspeeds consistantly greater than 30 mph. Additionally, there were no new 24-hour periods selected with cloudiness ≤ 5/10 when the wind-speed limit was increased from ≤ 30 mph to ≤ 45 mph.

The last set of two curves, Figures 29 and 30 reveals the dominance of cloud over wind as a principal factor in warming of the surface layers at the South Pole. 24-hour periods with winds between 16 and 30 mph were selected for both figures, but in Figure 29, cloudiness was ≤ 5/10 and in Figure 29 > 5/10. In Figure 29b, the statistical bias curve is nearly flat, but in Figure 30b it is concave and typical of the non-inversion situation. The mean temperatures were also slightly warmer in the latter non-inversion case. Windspeed remains a factor however, as can be noted from Figure 29 where the high windspeeds prevent the occurrence of a general inversion situation.

Figure 28a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15 mph; cloudiness > 5/10)

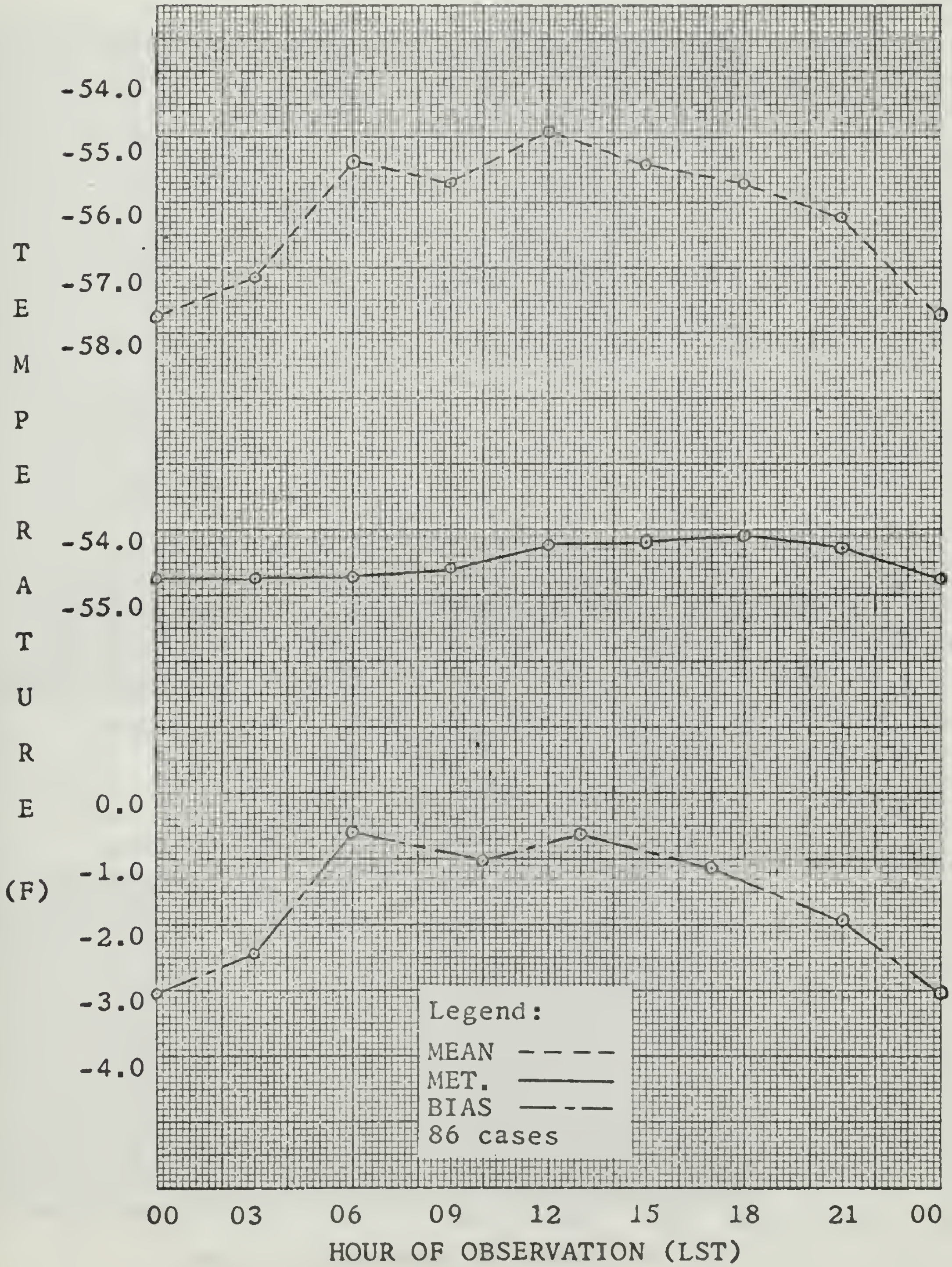


Figure 28b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15; cloudiness > 5/10)

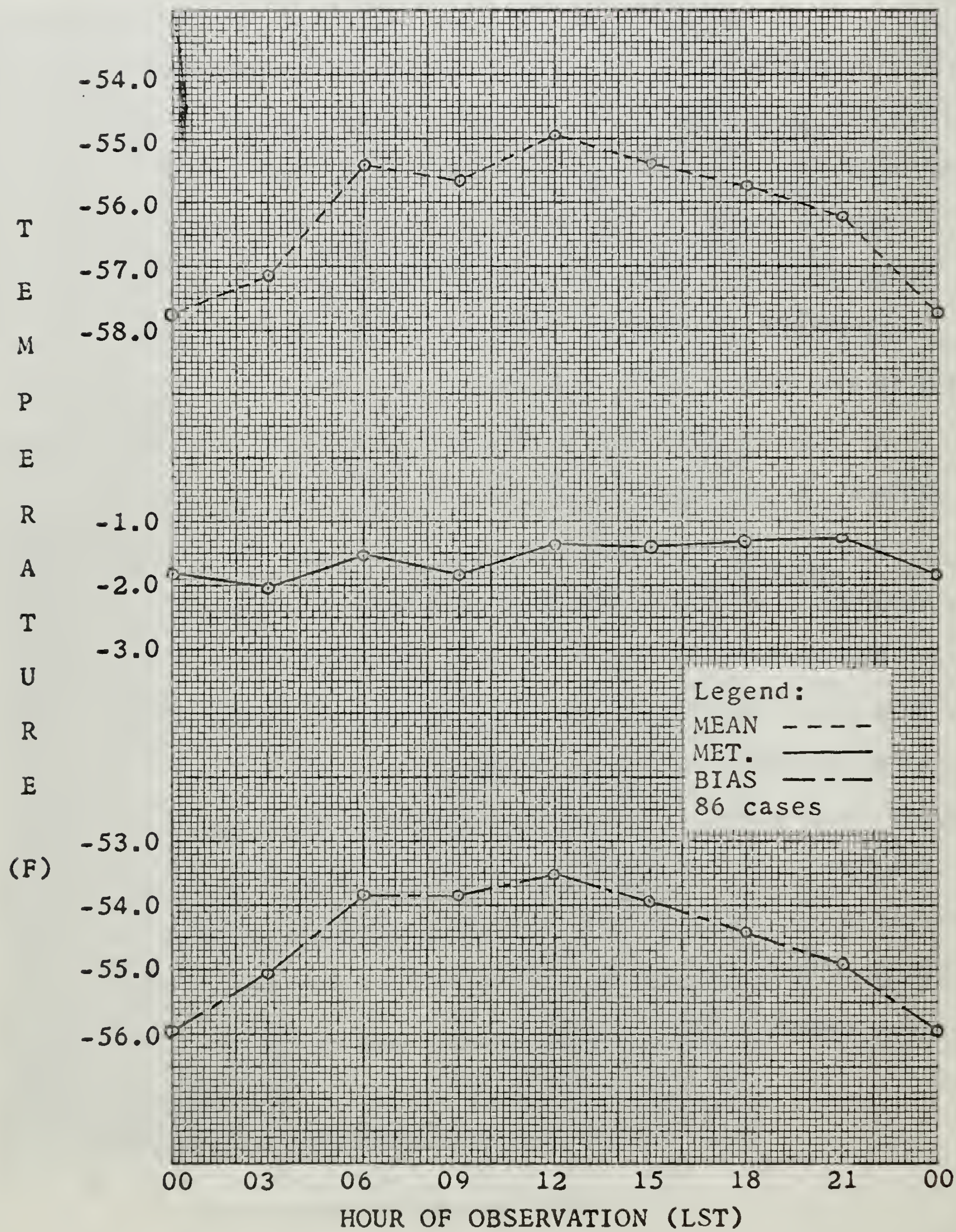


Figure 29a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15 and ≤ 30 mph; cloudiness ≤ 5/10)

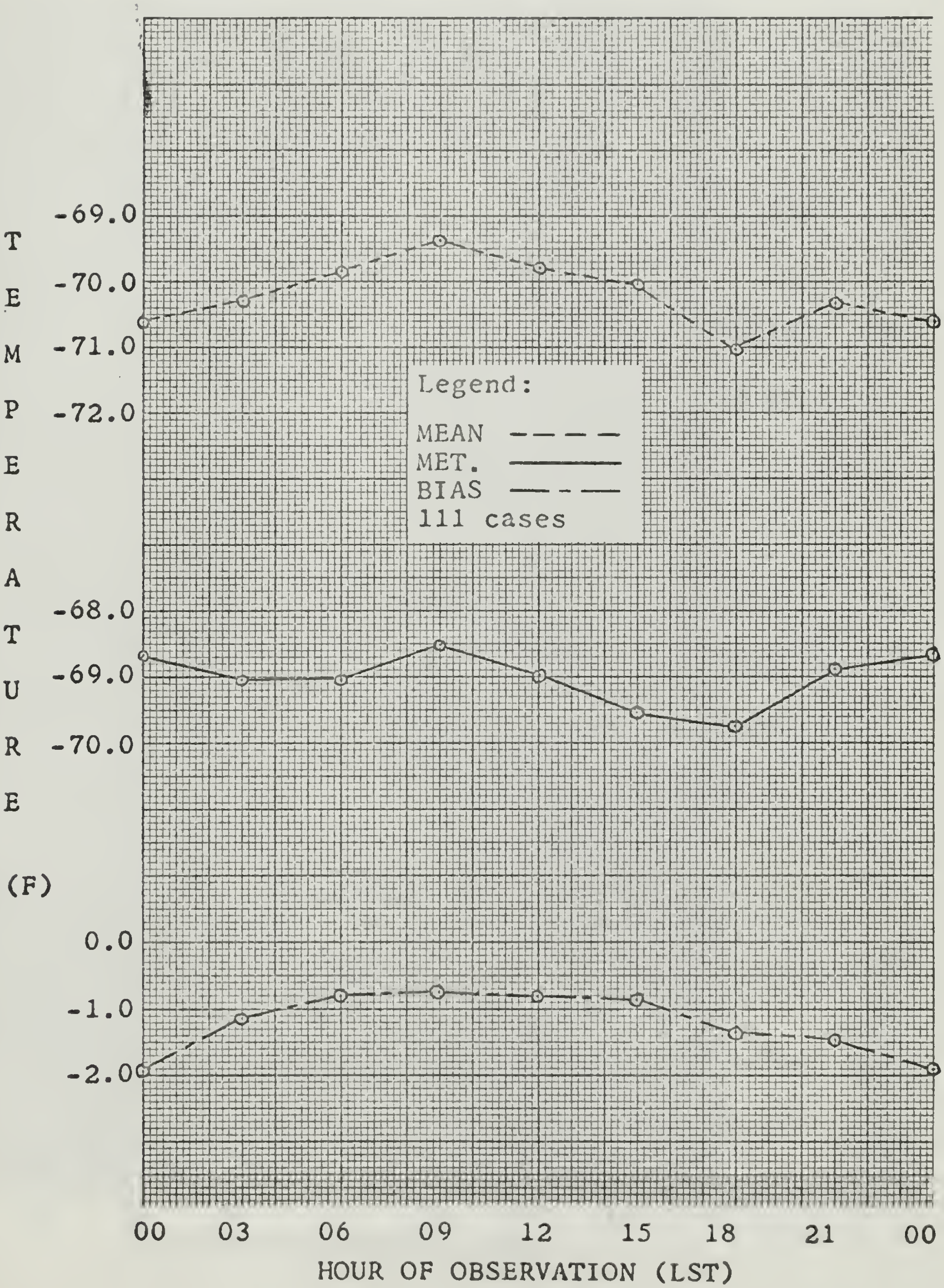


Figure 29b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15 and ≤ 30 mph; cloudiness ≤ 5/10)

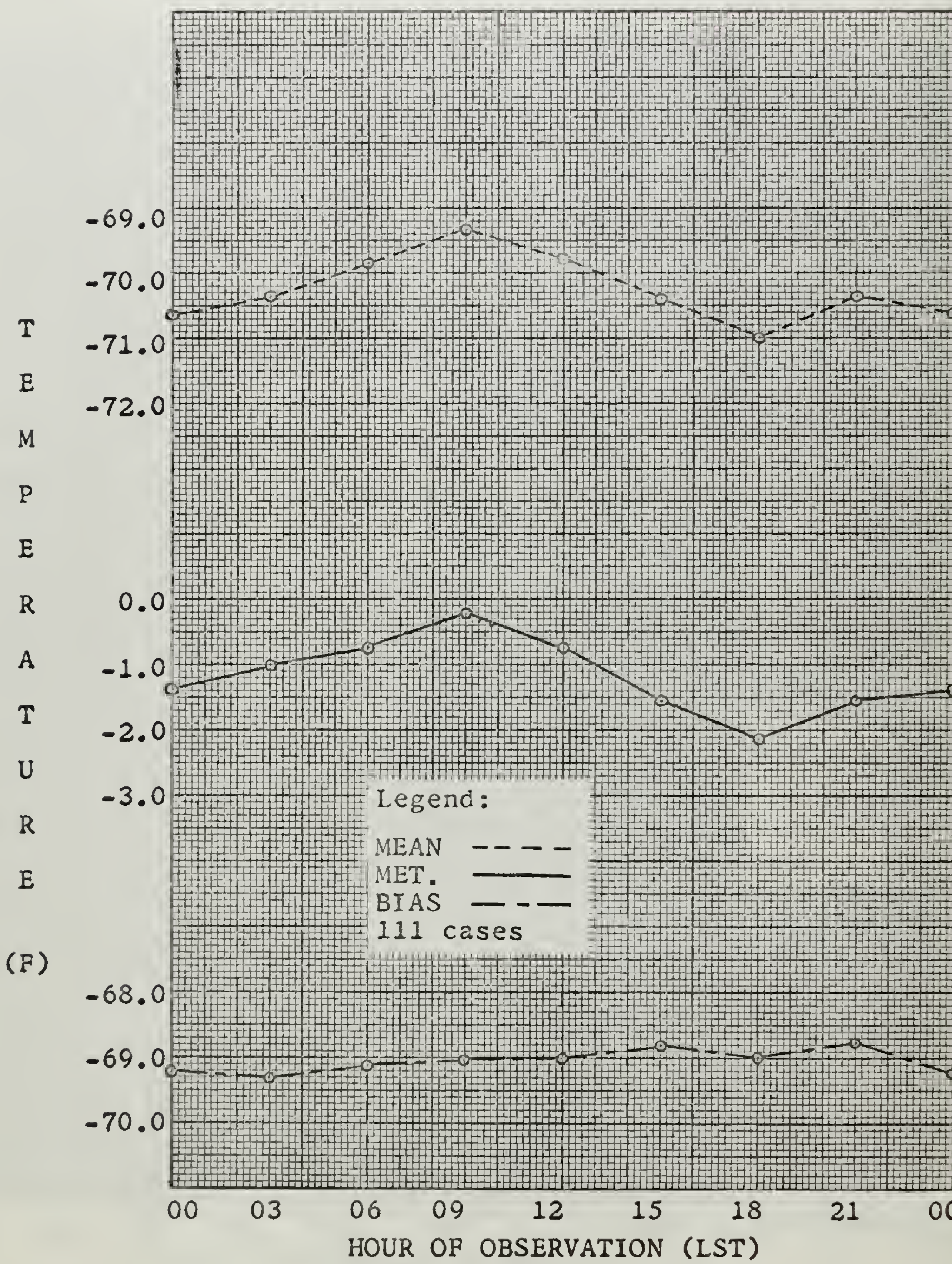


Figure 30a: Comparison of the mean 24-hour temperature variation with the column averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15 and ≤ 30 mph; cloudiness > 5/10)

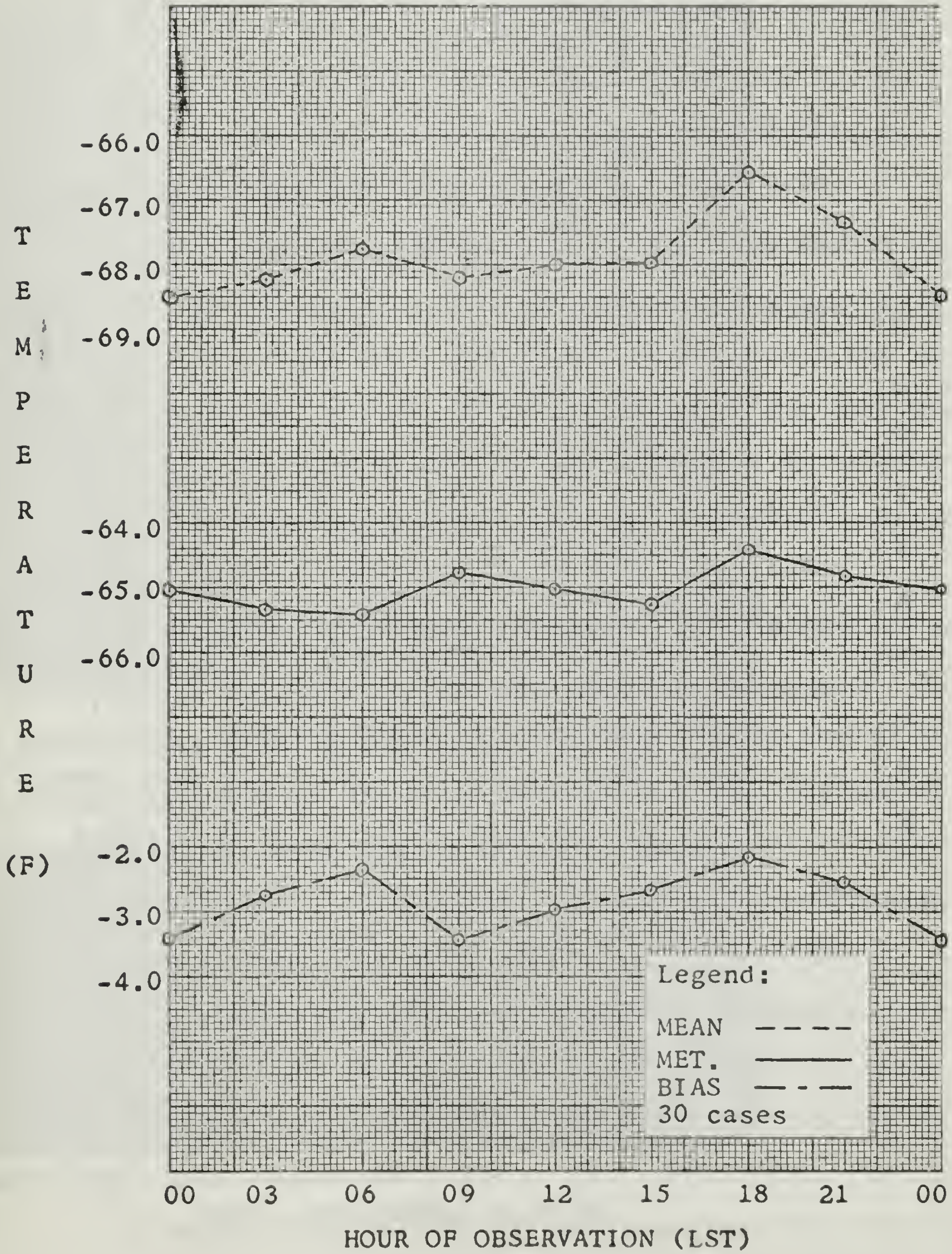
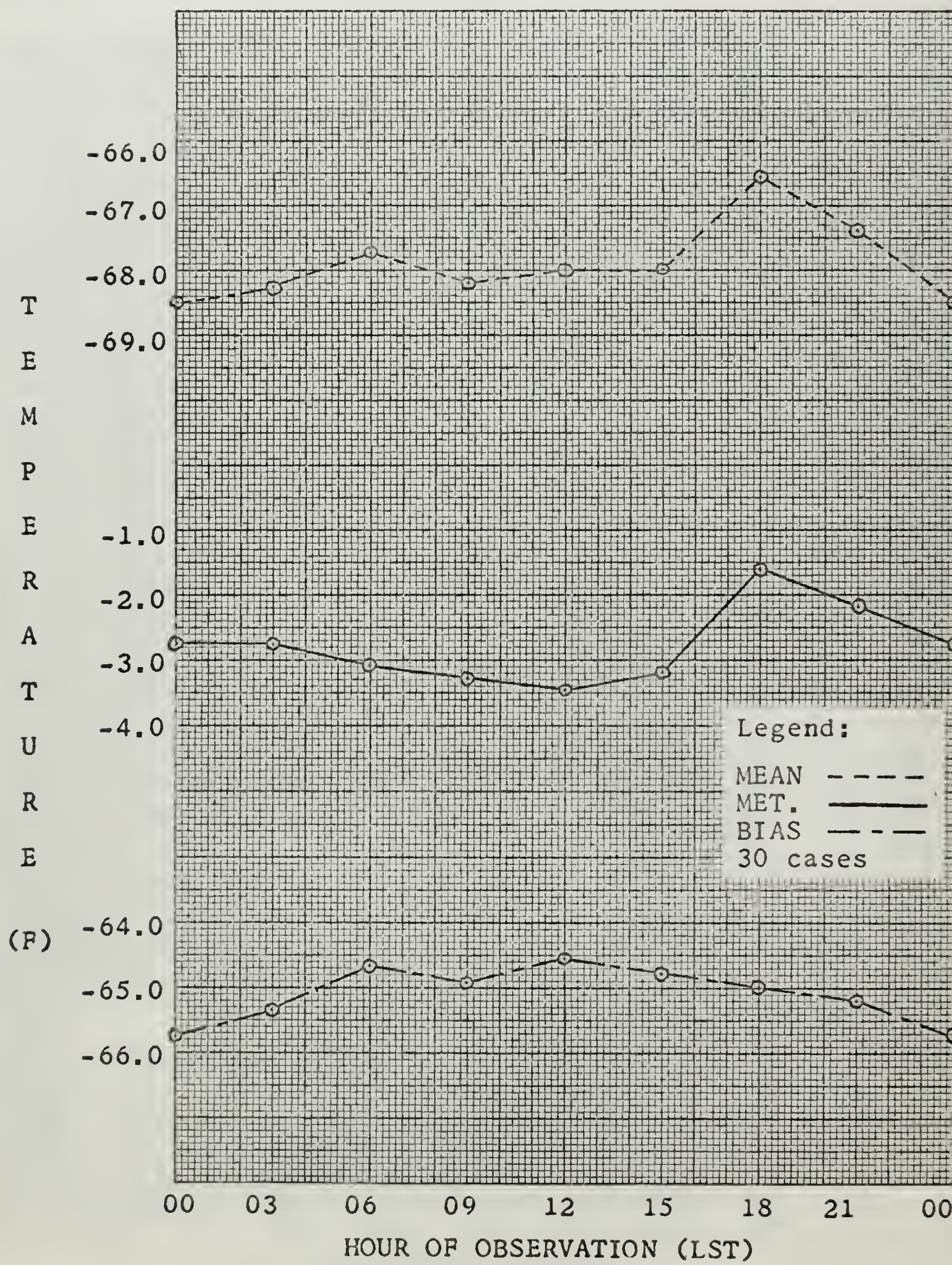


Figure 30b: Comparison of the mean 24-hour temperature variation with the diagonally averaged meteorological and the statistical bias variations at the South Pole.

(wind speed > 15 and ≤ 30 mph; cloudiness>5/10)



10. Conclusions and Acknowledgements.

The averaging all of the available data did not reveal a diurnal temperature variation during the polar night at either McMurdo Sound or the South Pole. It is concluded that previously reported diurnal variations were due to randomness in the data as a result of the investigators not having available a sufficient amount of data.

It was found that the mean temperature variations computed for specially selected days were considerably influenced by statistical bias, which when removed from the mean, left no consistent pattern of diurnal temperature variation. In addition, the data randomness is sufficient to warrant the use of both the column and diagonal averaging techniques in future studies.

During the polar night, the marked fluctuations in the long term daily temperature trend seem to result more from cloud cover variation than from the more normal atmospheric circulation effects and it is recommended that further investigation be conducted to determine more precisely the effects of cloud, windspeed and perhaps wind direction on the fluctuations.

It is recommended that the computer programs be modified to include the column and diagonal averaging computations and also that the computer graphing sub-routines be employed to plot graphs.

The authors wish to express their appreciation for the advice and guidance given during the conduct of this investi-

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13. ABSTRACT

This report is a continuation of an investigation begun at the U. S. Naval Postgraduate School in 1963, to determine whether or not a true Antarctica diurnal temperature variation exists and to determine the extent of statistical bias in modifying the mean temperature variations of specially selected days. In broadening the original study, the authors utilized an additional 12 years of data, a second geographical location and more accurate methods of obtaining results.

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